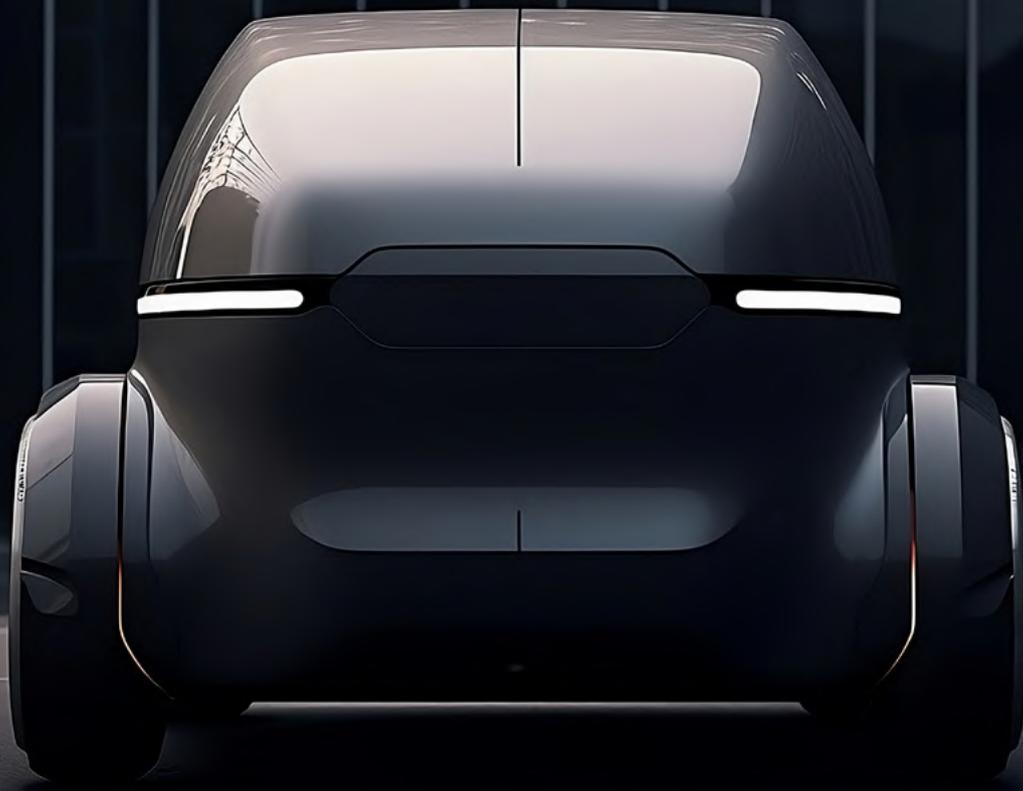


2023 AUTONOMOUS VEHICLE TECHNOLOGY REPORT

Examining the Latest Developments
in Self-Driving Vehicles



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He has significant experience working closely with large multi-national industries (e.g., IBM, INTRACOM, INTRASOFT International) as an R&D consultant and delivery specialist while being a scientific advisor to various high-tech startup enterprises. Dr. Soldatos is an expert in Internet-of-Things (IoT) and Artificial Intelligence (AI) technologies and applications, including IoT/AI applications in smart cities, finance (Finance 4.0), and industry (Industry 4.0).

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Foreword

In 2020, Wevolver launched its first Autonomous Vehicle Report that provided a comprehensive knowledge foundation about the technologies enabling autonomous cars. We are now pleased to launch a new report that surveys the advances in this arena over the last three years. Further, we provide a snapshot comparison of four leading AV companies, their tech stacks, and approaches to understand how these technologies are applied in actual use cases. The report is augmented with interviews with the report sponsors, who provide deeper insights into the current state of autonomous vehicles, highlighting their priorities, challenges, and leadership objectives.

The report examines autonomy from the perspective of passenger vehicles, following the approach of the previous report. However, many of the technologies mentioned are also relevant for other autonomous vehicle types that are making a significant impact in industries and applications such as lastmile delivery, warehouse and logistics, agriculture, mining, search and rescue, and healthcare. To create

this report, we interviewed dozens of industry experts and collaborated with technical researchers and writers from around the world.

We have attempted to cover all relevant technologies; however, due to space constraints, we had to limit some areas. This report was made possible by the generous support of its sponsors, the tireless effort of the Wevolver team, the expertise and generosity of our consulting experts, and the attention to detail of our writers, researchers, and designers. We hope you find value in this report, and we look forward to continuing to make this critical knowledge available for all.

State of the Art in Autonomous Vehicles Technologies

The core of this report is to make clear the current status of the technologies that form autonomous vehicles. We have separated the chapters into groups covering Sensing, where we take a closer look at the latest advances in cameras, LiDAR, RADAR, ultrasonic sensors, and emerging imaging radar technologies. The Thinking and Learning and Edge Computing chapters examine the dynamic landscape that encompasses advanced AI algorithms, natural language processing (NLP), machine learning techniques, and the transformative impact of edge computing.

Finally, we explore the technologies that ensure reliable communication, from rapid 5G Connectivity and dynamic Over-the-Air (OTA) Updates, to the use of Blockchain, as well as

Intrusion Detection and Prevention Systems (IDPS) and AI/ML-driven cybersecurity.

Each section highlights recent innovations, outlining why certain technologies have become dominant and gives examples of which companies are prominent in the area.

We provide some high-level definitions and explanations, but the first Wevolver report provides more fundamental knowledge of the technologies.

The report's final chapter looks at four leading autonomous vehicle companies: Waymo, Tesla, Cruise, and Volvo. We compare and contrast their tech stacks presenting a clear overview of the direction of the industry.

Sensing Technologies

At the cutting edge of autonomous vehicle (AV) technology, the confluence of advanced sensing modalities forms the cornerstone of vehicular autonomy. At the forefront of this confluence lies the integration of high-definition cameras with a suite of diverse sensors, including ultrasonic, LiDAR, and RADAR. This amalgamation, known as 'sensor fusion,' represents the zenith of current efforts to endow vehicles with perception capabilities necessary for full autonomous driving.

High-definition cameras, quintessential for their acute visual acuity and color discernment, play an indispensable role in this sensorial symphony. They excel in interpreting complex visual stimuli – from the nuanced hues of traffic lights to the intricate patterns of road signs. Yet, the prowess of cameras is not without its Achilles' heel; their performance can wane under the cloak of night or in the face of inclement weather. It is within these gaps that the orchestration of sensor fusion becomes critically imperative.

At the cutting edge of sensor integration, the marriage of ultrasonic sensors with LiDAR and RADAR is addressing the erstwhile shortcomings of standalone systems. This integration is particularly pivotal in surmounting the challenges of close-range detection – a realm where traditional LiDAR sensors often falter. Such precision in proximal perception is vital for executing complex parking maneuvers and navigating through constricted spaces with unerring accuracy.

The collaborative dynamics between ultrasonic and LiDAR sensors forge a more robust interpretative framework. While LiDAR imparts a detailed topographical map of the vehicle's surroundings, it is occasionally prone to misinterpretations, especially in the presence of reflective surfaces or atypical object contours. Here, ultrasonic sensors contribute a deeper dimension of spatial awareness, validating and refining LiDAR's data, thus mitigating the risks of erroneous object recognition.

Extending this synergy further, the integration of ultrasonic sensors with RADAR technology heralds a new era in perception systems capable of straddling the spectrum of short- and long-range detection. RADAR, with its broader wave patterns, often struggles with pinpoint accuracy in proximate scenarios. Ultrasonic technology deftly fills this void, granting AVs enhanced situational awareness – an attribute of paramount importance in scenarios that demand a harmonious blend of both near and distant perception, such as highway navigation interspersed with intricate parking sequences.

In this avant-garde realm, vehicle manufacturers are not merely choosing between sensor technologies; rather, they are strategically orchestrating an ensemble of LiDAR variants, each contributing its unique strengths to the collective sensory intelligence of AVs. The selection of specific LiDAR models is no longer a mere technical choice but a strategic decision, influenced by a myriad of factors including application-specific requisites, cost-benefit analyses, and the relentless march of technological innovation.

This chapter aims to delve into the intricate and sophisticated world of sensing and vision technologies in autonomous vehicles. We will explore how the nuanced integration of cameras with ultrasonic, LiDAR, and RADAR sensors is sculpting the frontier of autonomous navigation, steering us towards an era of unprecedented vehicular intelligence and autonomy.

Cameras and Vision systems

Cameras have a foundational and technically intricate position within autonomous vehicles, functioning as primary sensors to provide vital visual data for perception and navigation systems. Their role extends beyond mere image capture, encompassing intricate computer vision processes to interpret the surroundings with pixel-level precision. Cameras are instrumental in critical tasks, including real-time lane detection, object recognition, and complex depth perception, making them indispensable for AV safety and operational efficiency.

In the last three years, there have been significant advancements in high-resolution cameras, which have shown a remarkable increase in their ability to capture fine details. This, in turn, has enabled autonomous vehicles to accurately identify objects in their surroundings, making them more reliable and safe. Therefore, in this section, we explore developments in vision technology that have impacted AV development over the last three years.

3D Stereo Vision

3D stereo vision technology utilizes two cameras to determine the depth and precise positioning of objects in the environment. This is similar to how humans use binocular vision for depth perception. They are an integral part of the future of autonomous vehicles by enabling them to navigate roads more safely than single cameras.

The technology has seen rapid growth over the past decade, with significant strides being made by companies that are enabling automakers to quickly and inexpensively add 3D Stereo Vision to existing Advanced driver assistance systems (ADAS) with software solutions.

The positioning of cameras in vehicles is an ongoing topic within the industry. Wider-placed cameras have the potential to fall out of alignment when impacted by temperature shifts in the chassis or road vibrations - an issue when the cameras need to maintain an alignment within one-100th of a degree.

Major players, such as Subaru's EyeSight and the Drive pilot system in Mercedes' EQS, use stereo vision systems deployed in tighter formations to negate that - those systems are working in - tandem with RADAR. Stereo vision is an ever-growing technology, with researchers and developers exploring new ways to improve its accuracy, efficiency, and field of view.

The biggest impacts will likely come from deep learning and neural networks being used to handle occlusion and calibration issues. Other interesting areas of research include active stereo vision, which is being employed to project patterns or signals onto the scene, creating artificial texture and contrast.

Some of this cutting-edge research is being tested by university teams on the race track. For example, the Formula Student racing team of the University of Bayreuth is using Nerian's SceneScan Pro and the Karmin3 stereo camera to create a 3D stereo vision system for their autonomous racing car.^{2,3}



The 3D stereo vision deployed on the autonomous race cars. Image credit: Nerian.



A pedestrian crossing a dark suburban street. Visible light camera vs. FLIR® thermal camera captured by Foresight's test vehicle. Image credit: Foresight.

Thermal cameras

In the early 2000s, several notable car manufacturers, including General Motors, BMW, and Honda, blazed the trail by introducing passive thermal cameras to enhance safety during nighttime driving. These innovative thermal cameras were designed to address the dangers posed by animal collisions and the risk of pedestrian accidents in poorly lit or foggy areas. Their primary purpose was to provide invaluable assistance to human drivers.

However, the landscape of autonomous driving began to evolve significantly with the advent of the DARPA Grand Challenge. This competition sparked a surge of interest and substantial investment in various sensing technologies. Among them, LiDAR (Light Detection and Ranging) emerged as the frontrunner, capturing the lion's share of attention and financial support. Together with radar and visible cameras, this sensor suite gained widespread recognition as the optimal perception stack for achieving higher levels of autonomy.

In an effort to bolster their sensor

capabilities, certain companies are incorporating thermal cameras into their sensor suites, recognizing the unique advantages they offer in complementing LiDAR, radar, and visible cameras. This additional sensor modality proves invaluable in addressing specific challenges, such as identifying animals and humans in environments characterized by low light or heavy obscuration like fog, smoke, or steam.

Pedestrians are most at risk of an accident with a road vehicle after dark. More pedestrian fatalities occurred in the dark (75%) than in daylight (21%), dusk (2%), and dawn (2%).⁴

Notably, pioneers like Waymo Via and Plus.ai have harnessed the power of thermal cameras to advance autonomy in the realm of trucking, particularly on highways. By doing so, they are enhancing safety and efficiency in long-haul transportation.

Companies like Nuro, Cruise, and Zoox have adopted thermal cameras as part of their sensor repertoire for purpose-built vehicles designed to navigate the intricate landscapes of

densely populated urban areas. These vehicles are not only revolutionizing last-mile food and grocery delivery but also providing innovative solutions in the realm of ride-hailing services. Through the strategic deployment of thermal cameras, these companies are significantly elevating the safety and effectiveness of their operations within urban environments.

Harnessing AI-Enhanced Vision

Traditional cameras capture raw visual data, which requires subsequent processing and interpretation to derive meaningful information about the surroundings. AI algorithms, especially deep learning models, have revolutionized this process by enabling cameras to interpret visual information from their surroundings, enhancing their ability to comprehend images.

The integration of AI-enhanced vision represents a groundbreaking development that significantly improves the capabilities of camera systems in AVs. For example, HADAR, an AI-powered

thermal imaging system created by Purdue and Michigan State University researchers, provides clear thermal images by interpreting heat signatures. It significantly improves AVs and robots by resolving the blurring ,ghosting' effect seen in traditional thermal imaging.

Moreover, Omniq has recently launched a face detection feature for AVs, improving safety by recognizing faces to prevent crimes. Their AI uses neural network algorithms for smart decision-making and has already seen over 20,000 global installations. In a collaborative effort, SemiDrive and Kankan Tech are improving in-car imaging systems, where SemiDrive's X9 chip powers the systems and Kankan Tech provides comprehensive development services.

Kankan Tech has expertise in high-resolution cabin cameras and has developed a camera-based alternative to traditional rearview mirrors. They've

also introduced palm vein biometric recognition for AV access. The system, unaffected by lighting changes due to IR cameras, uses YOLO v7 algorithms for real-time face detection, analyzing facial expressions and head orientation for safety, with plans for commercial market integration after thorough testing.

Cameras, empowered by convolutional neural networks (CNNs) and appropriate classification ML techniques, enable AVs' vision systems to accurately identify and categorize objects, pedestrians, road signs, and lane markings. This level of understanding improves the vehicle's ability to make informed decisions in complex and dynamic traffic scenarios.

AI-enhanced vision is crucial in autonomous vehicles, encompassing tasks like object identification, motion tracking, and classification. This technology significantly augments AVs' understanding of their surroundings,

resulting in more informed and secure decision-making processes.⁵

An illustrative example of the potential of AI-enhanced vision comes from the research conducted at RIKEN in 2023. Their innovative approach, inspired by human brain memory formation techniques, involves degrading the quality of high-resolution images for training algorithms in self-supervised learning. This method enhances the algorithms' ability to identify objects in low-resolution images, addressing a notable challenge in the field of computer vision.⁶

Furthermore, researchers at Purdue University and Michigan State University have introduced a groundbreaking AI-enhanced camera imaging system known as HADAR (heat-assisted detection and ranging). HADAR utilizes AI to interpret heat signatures, effectively resolving issues such as ,ghosting' that are commonly associated with thermal imaging. Its applications span a wide

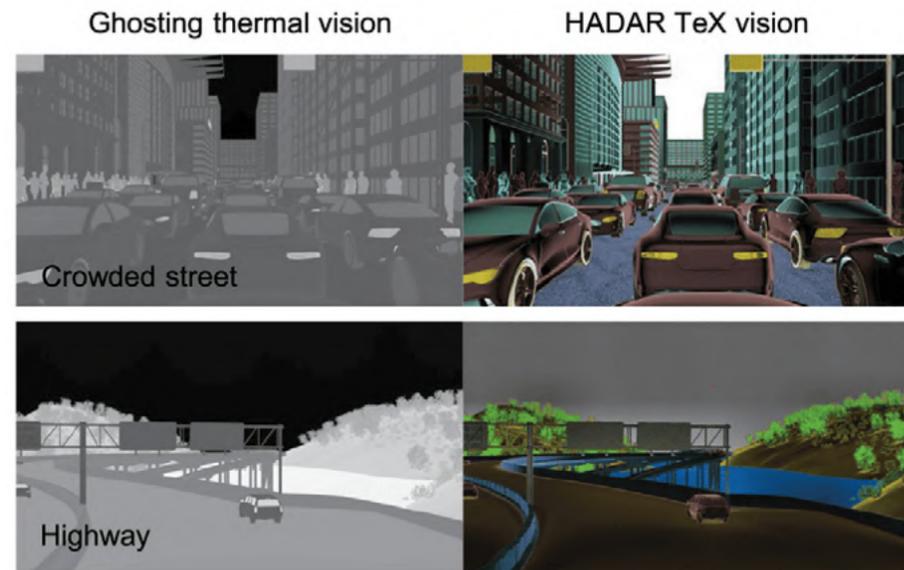
spectrum, from enhancing the perception of AVs and robots to enabling touchless security screenings at public events.⁷

Another example comes from NVIDIA, which has developed a pixel-level segmentation approach using a single deep neural network (DNN) to achieve comprehensive scene understanding. This technology can divide a scene into various object categories and identify distinct instances of these categories, as reflected in the lower panel's colors and numbers.

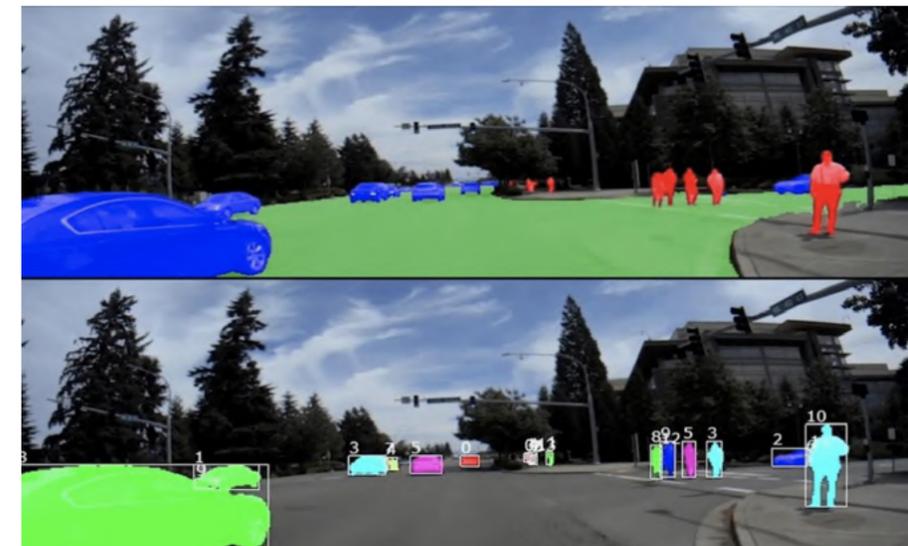
The benefits of this technology are far-reaching, including reductions in training data, improved perception, and support for the safe operation of autonomous vehicles. These innovations collectively underscore the transformative potential of AI-enhanced vision in shaping the future of autonomous vehicles and related technologies.⁹

“We have algorithms that are reading for lanes, but there’s also an object detection, but then there’s also a DNN we call free space. Which is looking for the absence of objects.”

Danny Shapiro, VP of Automotive at NVIDIA



Comparison between ghosting thermal vision and HADAR TeX vision. Image credit: NVIDIA



Panoptic segmentation DNN output from in-car inference on embedded AGX platform. Top: predicted objects and object classes (blue = cars; green = drivable space; red = pedestrians). Bottom: predicted object-class instances along with computed bounding boxes (shown in different colors and instance IDs). Image credit: NVIDIA

Prominent Companies Developing AV Vision Systems

This section highlights some of the cutting-edge vision systems currently enabling the development of AVs.

Mobileye

Mobileye uses a variety of cameras within its vision-based driver assistance systems, including fisheye cameras, wide-angle cameras, and thermal cameras.¹⁰ In 2023, Mobileye launched the first camera-based Intelligent speed assist that complies with the new EU standards. Their technology, which only uses cameras, has received official approval throughout Europe, making it the first of its kind. Mobil-

eye's technology can recognize various traffic signs, aiding Intelligent Speed Assist systems by using cameras alone. It relies on Mobileye's 400-petabyte database of global driving footage to swiftly meet increasing automotive safety standards.

Continental

Continental develops various cameras, including fisheye, wide-angle, and thermal cameras. These cameras are designed to meet the specific requirements of different AV applications. More specifically, the surround-view camera features fisheye optics for a short-range view, and it supports Ethernet or LVDS communication.

In November 2022, Continental and Ambarella entered a collaboration to

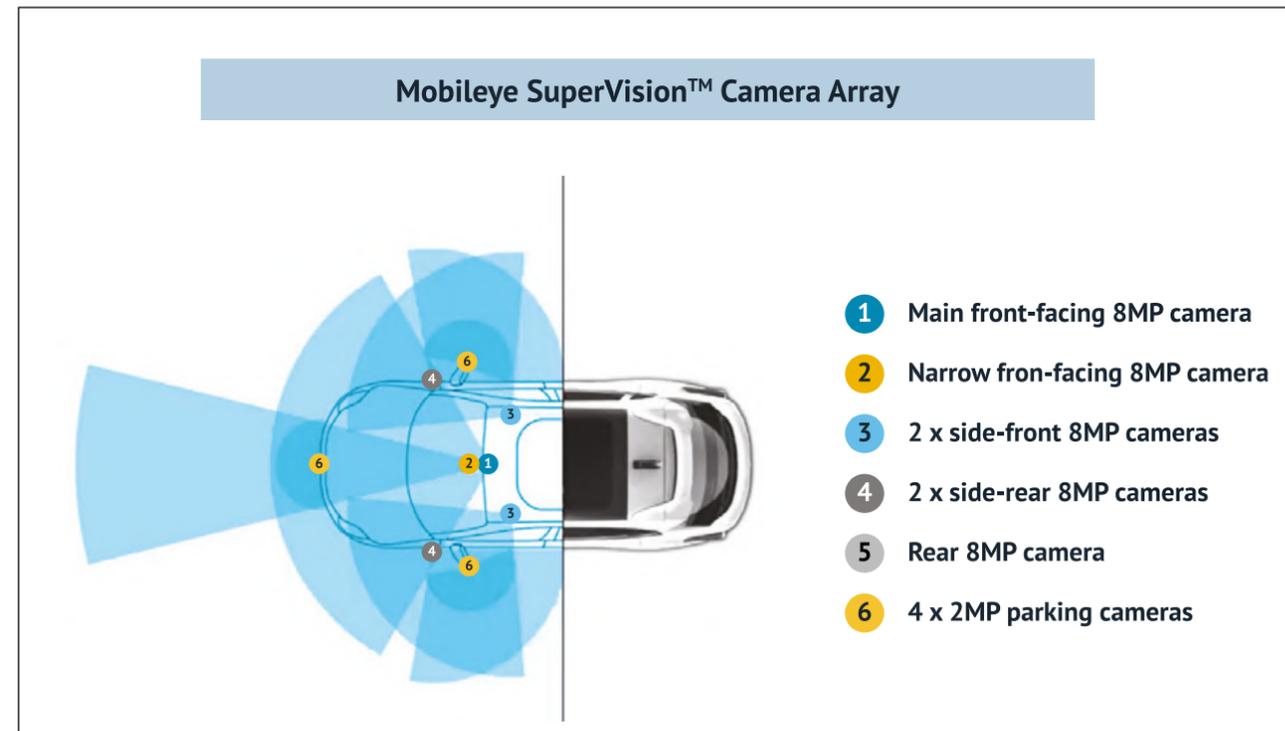
co-develop hardware and software solutions based on AI for assisted and automated driving. The partnership aims to produce products for global series production by 2026, addressing the increasing demand for assisted and automated driving technologies. The collaboration focuses on camera-based perception solutions for advanced driver assistance systems and scalable full-stack systems for vehicles with Level 2+ and higher autonomy.

TIER IV

TIER IV, is an open-source autonomous driving technology company who are their expanding production based on the huge interest in Automotive HDR Camera C1 which launched in 2022.



Continental's AV advanced camera solutions. Image credit: Continental



Mobileye SuperVision diagram presenting the components and coverage of the camera array. Image credit: MobileEye

The camera is designed for autonomous mobility applications and has gained widespread adoption in various fields, including autonomous driving, driver assistance, autonomous mobile robots, security, and surveillance. These applications are possible thanks to its impressive 120dB high dynamic range and high-quality automotive-grade hardware.

Over 100 companies worldwide have implemented the C1 Camera. Building on the success of the C1, in June 2023 TIER IV introduces the C2 Camera, a superior model with double the resolution at 5.4 megapixels, improving its capabilities in distant objects and signal recognition. Finally, TIER IV is developing the C3 Camera featuring an 8-megapixel image sensor to meet

the demands of high-speed applications such as highway driving. The goal is to complete its development within the year and start providing it in early 2024.

SPONSOR INTERVIEW



Mark Patrick

Director Technical Content, EMEA at Mouser Electronics

Accelerating AV Development Through Customer Collaboration

Mark, could you please describe your role at Mouser and the company's activities?

Mark Patrick: I oversee technical content for Mouser in EMEA. This role encompasses not just written content but also involves projects and event booth development aimed at engaging our primarily technical audience with relevant content and activities. Our goal is to both inspire and inform our audience, providing ideas and guidance on various projects, offering detailed instructions, code, hardware, and related materials. Ultimately, we are a technical distributor, supplying highly technical products to design engineers and component buyers. The technical marketing aspect is inherent in what we do, as authenticity is crucial when addressing our audience. This requires the collaboration of engineering and content teams. My background lies in semiconductors, technical sales, and application support. My engineering team consists of master's-level electrical engineering students from the Technical University of Munich. They are a young, dynamic team capable of diverse tasks.

Thank you for the introduction. Can you elaborate on Mouser's activities?

Mark Patrick: Certainly. In simple terms, Mouser is a global distributor with full authorization from all our manufacturers. We stock products from around 1,200 manufacturers, including well-known brands and specialized niche players. Our commerce platform allows anyone to purchase products needed for their development, design, or production processes.

You serve a wide range of customers, from OEMs to startups, correct?

Mark Patrick: Our customer base is diverse, ranging from individuals, including DIY enthusiasts often referred to as 'Fred in the shed,' to small consultancies, and up to large corporations and OEMs. This includes well-known companies like Google and Apple who seek the convenience of our services.

Could you tell us about Mouser's unique selling proposition (USP)?

Mark Patrick: There are other organizations similar to Mouser, but our USP lies in our focus on new product introduction. We lead our marketing efforts with the latest products and designs. We maintain over a million individual part numbers in stock at one location, ensuring a high-quality customer experience. This means that what you see on our website is readily available. We offer authentic and traceable components, a critical factor in light of recent supply chain concerns. Our vast inventory and commitment to offering new and innovative products set us apart.

How do you stay updated on the latest products and technologies?

Mark Patrick: We collaborate closely with our suppliers, maintaining a relationship that provides insights into their upcoming products and release schedules. We are prepared to create content, including technical details, for these products, ensuring we can go live as soon as the product hits the market. Additionally, we create content that becomes highly visible on search engines, helping customers find these new products quickly. This way, we facilitate access to technology and introduce it to new customers.

What are the benefits of Mouser's services for your customers?

Mark Patrick: Our customers, often engineers working on designs, require rapid access to products, particularly during testing, proof of concept, and prototyping phases. They need assurance that the products are readily available. We offer this level of trust through our website, in-stock inventory, and our ability to deliver products within two to three days worldwide from a single location in the US. This high-quality service hinges on the convenience and ease of finding products, combined with our informative and inspirational content.

With the increasing complexity of vehicles, particularly in the context of autonomous cars, how important is Mouser's service in providing the necessary technology and components?

Mark Patrick: Autonomous vehicles rely on various technologies, many of which require semiconductors for their functionality. The increasing capabilities and functionalities in modern vehicles are directly enabled by semiconductors. These components are now essential for even basic features like reversing cameras, navigation systems, audio systems, and safety features. Semiconductors play a critical role in processing the data generated by sensors and providing a seamless user experience. As the automotive industry continues to innovate, the role of semiconductors will only grow.

If an OEM needs a specific part that doesn't exist, can Mouser assist in facilitating the creation of such parts?

Mark Patrick: While we primarily stock standard products, we do collaborate with customers and tech support to address inquiries about specific components. However, for OEMs developing entirely new components, it is more common to work directly with manufacturers to create bespoke components, particularly given the scale of production in the automotive industry.

Regarding autonomous vehicles, do you think many of the underlying technologies and components are shared across different manufacturers?

Mark Patrick: Yes, there are common components and technologies that serve specific functions in autonomous vehicles, such as connectors, semiconductors, and sensors. Many of these components are not exclusive to a single manufacturer. However, there can be custom parts created for specific OEMs. In general, a wide range of standard components can be used to build various aspects of autonomous vehicle systems, with the focus shifting more toward software and user experience differentiation.

When do you anticipate mass rollout of fully autonomous vehicles, and what are the main challenges to overcome?

Mark Patrick: The rollout of fully autonomous vehicles is already happening to some extent, particularly at level two, where we see vehicles with various assistance features. To achieve higher levels of autonomy, there are technical, ethical, and social challenges to address. Technically, the necessary processing power and machine learning algorithms are increasingly available. Social acceptance of driverless cars and ethical considerations, such as decision-making in complex situations, remain areas of concern. While trials of fully autonomous vehicles are ongoing, predicting when they will become mainstream is challenging. However, we may see more of these services in cities across the world in the next five years.

Before fully autonomous vehicles become commonplace on the road, do you expect them to be used in controlled environments, like ports, airports, or factories?

Mark Patrick: Yes, we are already witnessing the use of autonomous technology in controlled environments, such as autonomous ground vehicles and robots. In these settings, the technology is more readily accepted and deployed. The same principles can be applied to larger-scale deployments in defined geographical areas with established infrastructure. Controlled environments with specific infrastructure and limited interaction with the general public are more suitable for early adoption. Industrial facilities and warehouses are already leveraging autonomous technology for efficiency.

Is there anything else about Mouser or your role that you would like to mention for the report?

Mark Patrick: Our primary role at Mouser is to enable access to technology. We work

closely with our suppliers to ensure that those working on advanced systems have access to the technology they need, whether it is high-end processing power, sensing technologies, or a wide range of components. We offer a comprehensive range of products that can be used to build end-to-end systems. Essentially, we aim to provide everything customers need to develop their projects, from individual components to complete kits, making the process of accessing technology as straightforward as possible.

LiDAR

LiDAR (Light Detection And Ranging) sensors help autonomous vehicles to sense and understand their surroundings. They use laser pulses to detect and measure the time it takes for the reflected light to return, compiling this data to create 3D mappings of its environment. This information is then combined with other data to ensure safe navigation.

A core area of current LiDAR research is developing systems that combine the strengths of different LiDAR technologies to improve overall perception performance. Pairing pulsed LiDAR with FMCW LiDAR, for instance, pro-

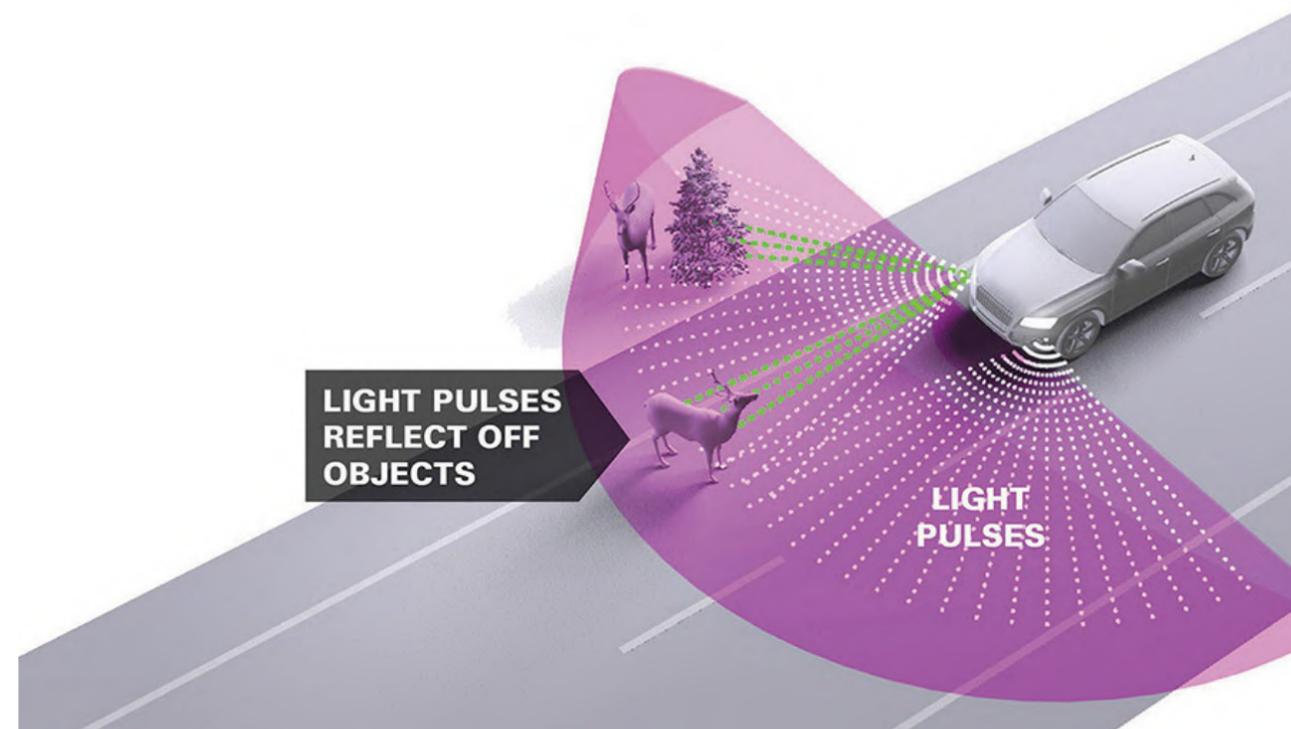
vides comprehensive object detection, accurate distance measurement, and real-time velocity estimation.

A hybrid LiDAR setup could integrate a solid-state laser for short-distance assessments alongside an FMCW laser optimized for capturing distant measurements. Integrating LiDAR with other sensors like cameras and RADAR creates a sensor fusion ecosystem that can address sensor redundancies and data gaps, ultimately improving the robustness and reliability of autonomous driving systems.¹¹

LiDAR Product Overview

Solid-state LiDAR

Solid-state LiDAR systems use non-moving optical components to steer laser beams, making them well-suited for the stringent requirements of AVs.^{12 11} Launched in 2018, solid-state LiDAR can enhance sensor range by more than 200 meters while reducing costs by more than ten times. They offer a promising advantage over conventional LiDAR that steers an optical beam using moving parts. The assembly and alignment of these moving parts are expensive and raise significant concerns about their long-term dependability.



LiDAR light pulses covering object on the road. Image credit: Delphi

The demand for solid-state LiDAR is expected to grow at a CAGR of 30.66% over the forecast period of 2021-26. This potential growth is reflected in the high volume of research in this area, including the emerging area of nanophotonics-based LiDAR sensors.

Automotive brands like Velodyne (now Velodyne + Ouster) and tech companies like Luminar & Xenomatrix are advancing solid-state LiDAR research. With OEMs like Mercedes Benz entering deeper partnerships in the solid state LiDAR space.

Frequency-Modulated Continuous Wave (FMCW) LiDAR

Frequency-Modulated Continuous Wave (FMCW) LiDAR works by emitting a continuous laser signal with a modulated frequency, which enables simultaneous distance and velocity measurements.¹¹ This real-time capability is crucial for AVs to accurately assess dynamic environments. FMCW LiDAR's continuous waveform provides higher resolution, enabling fine-grained object detection and tracking.

Although signal processing complexities exist, research in this field rapidly advances, promising improved perception for AVs. It has been recognized as a transformative advancement in LiDAR technology. Pioneering companies like Aeva, Mobileye, and Blickfeld have dedicated extensive years to developing Photonic Integrated Circuits (PICs) and FMCW sensors, poised to revolutionize the landscape of autonomous driving.^{13 14}

Companies Developing LiDAR Technologies for AVs

In this section, we go deeper into the companies at the forefront of advancing LiDAR technology for AVs.

Velodyne

Velodyne is a prominent provider of LiDAR sensors developed for AVs. It is the first LiDAR company to go public. The company asserts itself in the automotive industry by working closely with customers to test its LiDAR sensors based on common sets of real-world scenarios and relevant corner cases. In February 2023, Velodyne merged with Ouster. Major players in the AV industry, such as Waymo, Uber, and Cruise, utilize Velodyne's LiDAR sensors.¹⁵

Luminar Technologies

Luminar Technologies develops vision-based LiDAR and machine perception technologies, primarily for autonomous vehicles. In February 2023, Luminar, launched Iris Plus, a LiDAR sensor designed to blend into the roofline of a production vehicle. It uses laser light waves longer than usual, at 1550 instead of the common 905 nanometers. This feature improves the device's ability to detect small and low-reflective objects, including dark-colored cars, animals, or a child suddenly running into the street. It operates at distances exceeding 250 meters and up to 500 meters for larger, more reflective objects.

Mercedes plans to be among the first car manufacturers to incorporate Luminar's Iris Plus LiDAR into its production vehicles. Mercedes and Luminar announced their partnership in Janu-

ary 2022, initially aiming to integrate Luminar's LiDAR into a single high-end vehicle model. Since then, plans have expanded significantly, with Mercedes aiming to increase its LiDAR supply by ten times over the coming years. Big-name companies like Volvo, Toyota, and BMW also employ Luminar's sensors.^{16,17}

Aeva Technologies

Aeva Technologies pioneers LiDAR sensors with capabilities in both visible and infrared spectrums. Uber and Continental are among the companies adopting Aeva's technology. In 2022, Aeva released its revolutionary 4D LiDAR technology Aeries II, which employs FMCW4D technology and the LiDAR-on-chip silicon photonics design. Aeries II is compact, configurable, and automotive-grade, designed for reliability across various conditions.

With ultra-long-range object detection and tracking capabilities of up to 500 meters, it stands out in detecting oncoming vehicles, pedestrians, and animals. Additionally, Aeva's FMCW technology remains unaffected by interference from sunlight or other LiDAR sensors, and its LiDAR-on-chip design enables scalable production for a wide range of autonomous applications.¹⁸

Quanergy Systems

Since 2022, Quanergy is transforming physical security, which plays a crucial role in enhancing situational awareness and safety in driving, with its real-time 3-D LiDAR solutions. The company is pioneering in providing 3-D LiDAR security solutions that bring intelligent and proactive awareness to dynamic environments. Quanergy aims to empower users to transcend current sensing limitations, offering an experi-

ence of 3-D security tailored for a 3-D world. Toyota and Geely are among the companies incorporating Quanergy's sensors into their AV products.^{19 20}

Intel and Mobileye

Since 2020, Intel and Mobileye have a specific focus on enhancing the performance of LiDAR and RADAR sensors for AVs by leveraging technologies such as PICs and FMCW LiDARs. They are focussing on hybrid LiDAR-RADAR solutions aiming to capitalize on the strengths of both technologies. The proposed architecture involves the integration of cameras, LiDARs, and RADAR to cover the full field of view, aiming to overcome challenges like side lobes and limited range in traditional sensors.^{21 22} The collabo-

ration between the two companies aims to make Radars and LiDARs both better and cheaper in order to reach L5 autonomy more quickly. Their new product range is expected to launch in 2025.

Continental

Continental's High-Resolution 3D Flash LiDAR technology marks a significant advancement in vehicle vision. Released in 2021, this LiDAR system boasts a solid-state design, ensuring continuous data flow without gaps. Its high-resolution capabilities span both vertical and horizontal dimensions, offering detailed insights. The system also includes features like blockage detection, an integrated heater, an optional washing system, auto-align-

ment, and continuous sampling mode.^{23 24}

Blickfeld

Blickfeld introduced the Qb2 smart LiDAR sensor in 2022, a novel device designed for easy deployment due to its onboard processing and Wi-Fi connectivity. This marks the first smart LiDAR sensor featuring built-in software. The Qb2 LiDAR sensor merges high-performance detection and ranging capabilities with onboard software, enhancing performance and setup efficiency without any complex custom software to be developed.

Additionally, the sensor includes built-in Wi-Fi support. The Qb2 employs a custom micro-electro-mechanical

systems (MEMs) mirror for beam steering, optimizing the balance between resolution, range, and field of view to create multi-dimensional maps. Achieve a maximum of 400 scan lines per frame, guaranteeing exceptional quality in-point cloud data. The Qb2 sensor is designed to accommodate three returns and boasts a laser beam divergence of $0.25^\circ \times 0.25^\circ$, facilitating meticulous scanning for precise, dependable, and reliable information.^{25 14 26}

Hesai Technology

Hesai Technology offers a variety of LiDAR sensors designed to meet the requirements for Level 4 and higher autonomous driving, which ensures reliable and safe operation. On August 1, 2023, Hesai Technology announced its partnership with NVIDIA. This collaboration aims to integrate Hesai's advanced LiDAR sensors into the NVIDIA DRIVE and NVIDIA Omniverse platforms, setting the stage for groundbreaking developments in autonomous driving. By bringing together Hesai's specialized LiDAR technology and NVIDIA's expertise in AI, simulations, and software development, this partnership promises to drive innovation in the AV sector.

RoboSense

RoboSense offers various Smart LiDAR perception system solutions based on three fundamental technologies: chips, LiDAR hardware, and perception software. In 2016, RoboSense began working on mechanical LiDAR, known as the R platform. By 2017, they had introduced perception software and the M platform. In 2021, RoboSense achieved the start of production for the M1, becoming the first LiDAR company globally to mass-produce automotive-grade LiDAR with internally

developed chips. In 2022, to improve the M platform product range in the automotive LiDAR field, RoboSense introduced the E platform, a blind spot solid-state LiDAR. OEMs that implement RoboSense solutions are BYD, GAC MOTOR, SAIC Motor, Geely, FAW, Toyota, Baic Group, and many others.



Continental's High-Resolution 3D Flash LiDAR.
Image credit: Continental

SPONSOR INTERVIEW



Theresa Hackl, Application Marketing Engineer at Murata
Komei Takura, Senior Business Development Manager for Mobility
Yoichi Murakami, Senior Product Manager for Function Devices

Building Trust in Autonomous Driving: Navigating Future Reliability and Milestone Achievements

In your role at Murata and from the viewpoint of a component supplier, can you provide an overview of the current state of the autonomous vehicle industry?

Theresa Hackl: There's a lot going on in the autonomous vehicle industry these days; lots of development and testing. Many manufacturers (OEMs) and many tech companies are involved. Recently, there were also many news about OEMs collaborating with IC companies and even Tier 1s. Focusing on what's happening on the road today, you can see Level 2 (partial automation) or Level 2+ (L2 with enhanced ADAS) cars, additionally to the "standard" cars with no (Level 0) or just simple ADAS functions (Level 1). There are also instances where Level 3 (conditional automation) has been granted. For example, the Mercedes S-Class has been granted L3 autonomous driving in Germany end of 2021 (with market release in spring 2022) and since early this year also in the US in some regions, under certain conditions. This still faces some challenges, but maybe we can discuss them later. As for Level 4 (high automation) or more highly autonomous driving, these would be found in robotaxis, operating now for example in San Francisco, California.

These driverless cars have been allowed to operate 24/7. However, just recently, it was announced that there will be a limit on the number of driverless cars allowed to operate in San Francisco due to an accident, where an autonomous vehicle collided with a fire truck. As a result, they reduced the number of autonomous vehicles allowed to operate to fifty per day (and 150 during nighttime). Basically, you can see there are still some limitations to using autonomous vehicles and operating them.

Komei Takura: I'd like to add something here. In terms of the mindset, you can see quite a difference between Europe, the US, and China. I joined a conference in the US a month ago. The feeling was that Level 4 or Level 5 cars would be on the road in about two years. The acceptance and belief in this is quite amazing compared to the mindset

here in Europe. In China, for sure, they want to go even further. I mean, they want to take initiatives to be world leaders technology-wise. The willingness to develop faster is quite different from what you see in Europe, which is quite interesting.

How do you see Murata's current product portfolio integrating with the evolving needs of autonomous vehicles?

Theresa Hackl: Well, as a component manufacturer, Murata can be found in various sensors like cameras, LiDAR, RADAR, etc...and also in ECUs - the brains of the vehicle. For example, for a Level 3 car equipped with all the sensors and technologies needed for safe driving, Murata could provide up to 8,000 components, including passive components like capacitors, inductors, and thermistors. These cover just the ADAS functions. As for electrification, an electrified car or a connected car would, of course, have many more components on top, like our Bluetooth and Wi-Fi modules.

Komei Takura: The number of components has been really, really increasing quite a lot. At first, there used to be about 1,000 components or so. The combustion engine didn't have an ADAS system. Our main business for automotive is IVI ([in-vehicle infotainment](#)), but the number of components has been increasing rapidly from about 1,000 to an expected 15,000 or even 20,000 components per car for EVs with ADAS functions in the next 3-4 years. That's a significant change.

What are the main challenges that you feel still exist in achieving fully autonomous vehicles, and how is Murata working to address those challenges from your perspective?

Theresa Hackl: There are many challenges. One is, of course, regulations. Each region and country has its own regulations. In the US, it's even more fragmented than here in Europe, where, I believe, it seems quite good, as we have particular regulations that allow autonomous driving under certain conditions. But there are also technical challenges to consider. You need to have redundancy and fail-safe operation of sensors as they work together. There are infrastructure needs, where you would need to ensure the communication between the sensors and also between vehicles.

With that, safety concerns arise. Generally, you need to ensure that the sensors are working well under all conditions, no matter what the weather is or what may happen during operation. This also leads to other issues to consider, such as ethical concerns, legal issues, and consumer acceptance. Basically, there are a lot of challenges to be addressed, not to mention that people also need to feel safe while using an autonomous vehicle. Of course, each manufacturer has to address such challenges carefully.

As for Murata's involvement, we are mainly component-oriented, but we also communicate and collaborate with a lot of partners and industry players. We keep aware of what they need and we also contribute to the safety concerns. In the end, it's more on

the side of the vehicle manufacturers and tech companies to ensure and spread the acceptance of safe autonomous driving.

Furthermore, Murata also contributes to the trend in the automotive industry towards size and weight reduction by downsizing the sensors or ECUs. In fact, about 90% of autonomous miles in California are already supported by Murata's inertial measurement units (IMUs).

Komei Takura: There are many tests for autonomous driving over there in California, like what Waymo and some others are doing. They of course need high accuracy and high performance. Murata's IMU is a dead-reckoning sensor, and customers need such a high-accuracy solution, especially to ensure safety in this market. When the market develops in a later stage, the entire system may mature, and thus the number of sensors could be reduced a bit, but accuracy remains the key, anyway. That's why we believe that companies will keep selecting our solutions.

How important is the role of partnerships and collaborations in the evolution of autonomous vehicles? Can you share some insights into the kind of partnerships Murata is pursuing?

Theresa Hackl: As I mentioned earlier, we read in the news all the time that Qualcomm is collaborating with this OEM or with that OEM...Tier 1s are working with this OEM and providing this and that. Partnerships and collaborations play a crucial role here in evolving autonomous vehicles and combining the strengths of each party. Murata is, of course, in contact with all of these stakeholders to have a better outline of the ecosystem, what's going on in the market, and to also be able to provide the best solutions. One collaboration, for example, is with system integrators like Nordic Inertial.

Yoichi Murakami: With regards to [Nordic Inertial](#), we invested in this company because they focus on the algorithm along with how to use our sensor inside of a vehicle. For future autonomous driving, algorithm understanding is one of the key aspects, and this is more easily achieved using our high-performance sensor. This is just the start. In the future, we'd like to do such collaborations with other players in the market in order to establish the value of the Murata sensor in the market.

Komei Takura: Speaking about the general autonomous driving market, collaborations aimed at software development are really important for our customers, especially OEMs. This is quite common, but for Murata specifically, we collaborate with software companies and system integrators to be an integral part of the ecosystem of autonomous vehicle customers.

How is Murata staying ahead of the curve in predicting and adapting to changing requirements, and what R&D initiatives are currently in place to ensure the company remains a leading player in the mobility sector?

Theresa Hackl: Our most important philosophy is to provide high-quality products. We believe that's one of the main reasons Murata is chosen and what we are well-known for. Of course, we will continue to keep developing these cutting-edge products with high quality while also adapting to the market needs and trends.

In the future, we would also like to go more into the solution business by working together with OEMs, IC design houses, and system integrators. Through our module and mobile phone business, we already have a good relationship with IC makers, so we can build on that.

Can you share some insights about Murata's roadmap for the next 5 years in the autonomous vehicle sector?

Theresa Hackl: Of course, we will continue to go along with the downsizing trend, but we also want to focus more on the application itself and not just on a single product. We aim to become a solution provider, specifically in terms of the sensor portfolio, and then be able to provide our customers with a concrete solution instead of just a single capacitor, inductor, etc.

Komei Takura: Yes, speaking of sensors, we were an element supplier for ultrasonic sensors. We can be a module supplier. With algorithm, we can also become part of a system supplier. In the coming years, we want to be more integrated with the module, with algorithm, as a solution provider. That's one of the sensor trends for the upcoming years.

As the automotive industry pushes for the democratization of autonomous features across all vehicle tiers, how is Murata working to make sensors more cost-effective for mass-market adoption?

Yoichi Murakami: A little bit back to the basic things. Murata is a unique company. Product manufacturing is key. At Murata, we distinctly focus on manufacturing processes on our premises. Why? Simply, to make a high-quality product, we need to fully understand material and how to manufacture the product, and the best way to do so is to have the manufacturing site on company premises in order to have complete clarity of the manufacturing process. That is a key philosophy of Murata's. Murata sticks to manufacturing. That is why it's called Murata Manufacturing.

While many companies create their designs and miniaturized products without fully understanding the key parameter of manufacturing, Murata provides the manufacturing on its premises. This is one of our major advantages. Murata enables miniaturization with high-quality manufacturing of high-performance components. Even though the market requires cost reduction, quality remains the number-one priority, and Murata proudly provides that.

One of the key challenges for sensors in autonomous vehicles is operation in adverse weather conditions like fog, rain, or snow. How is Murata addressing these challenges to ensure consistent and reliable sensor performance?

Theresa Hackl: To address the challenge for sensors to perform in all weather conditions, we are currently developing an ultrasonic cleaning device that keeps devices clean and reliable. The main focus for this product is the camera application, but it could also be adapted in the future to other systems, like LiDAR, for example.

With the vast amounts of data generated by autonomous vehicle sensors, how is Murata approaching on-chip or near-sensor processing?

Komei Takura: Well, while we're not a system supplier, maybe I can answer you from our passive-component-supplier viewpoint. One way we are contributing to data processing quality and speed is with our noise filters, which help reduce noise and smoothen the data processing. We've been working with standard bodies to apply these products to areas like Controller Area Networks (CANs) and ethernet. Based on the corresponding requirements, we collaborate with OEM customers and make sure that even small components they need to qualify can be used properly, as these will contribute to better their gateway performance.

That's one example. Of course, talking about ADAS ECU, and high-speed processing, as Theresa already explained, we've been working with known semiconductor companies. These companies need thousands of components for their chipsets. We support their design activity as a passive component supplier.

What can people expect in terms of the sustainability and longevity aspects of your products? What is your approach to sustainability in your product portfolio?

Yoichi Murakami: Of course, there are basic things. In Murata, we comply with the quality requirements and standards, like [ISO and IATF](#). We also conduct the very-severe-condition testing inside Murata because reliability and quality are key in a Murata product. One key idea to keep in mind, especially in new areas like autonomous driving, is that no one knows exactly what kind of reliability requirements are going to be in the future. For that reason, we need to think ahead a little more and base that on the current situation. The most important point is to establish trust with vehicle vendors and customers who will be using autonomous vehicles in the future. As Theresa mentioned earlier, 90% of autonomous driving mileage in the US was realized with the Murata IMU sensor, - a good indication of our product reliability.

Komei Takura: Just to iterate on the trust and quality aspect. As many people know, from time to time there are recalls and problems of car models. In order to ensure our

customers' parts selection, we are supporting OEMs and Tier1s by providing all the reviews of their BOMs and the right components from both the quality viewpoint and the long lifetime viewpoint. Otherwise, they may not pick the right parts, which can be an issue for the automotive sector, where it's not easy to switch components in the middle of a mass production period. Such kind of support is also contributing to the quality on a system level, which would also help on the market level to ensure trust by the consumers.

Visit [Murata's website](#) for more information about their product portfolio and their leading contribution as a component supplier to the evolution of AV technologies.

Note: Since this interview Cruise has had its licence [revoked](#) following an accident.

'Autonomous vehicles navigate the road of innovation, driven by the promise of a safer, more efficient, and greener interconnected future.'

Theresa Hackl

RADAR

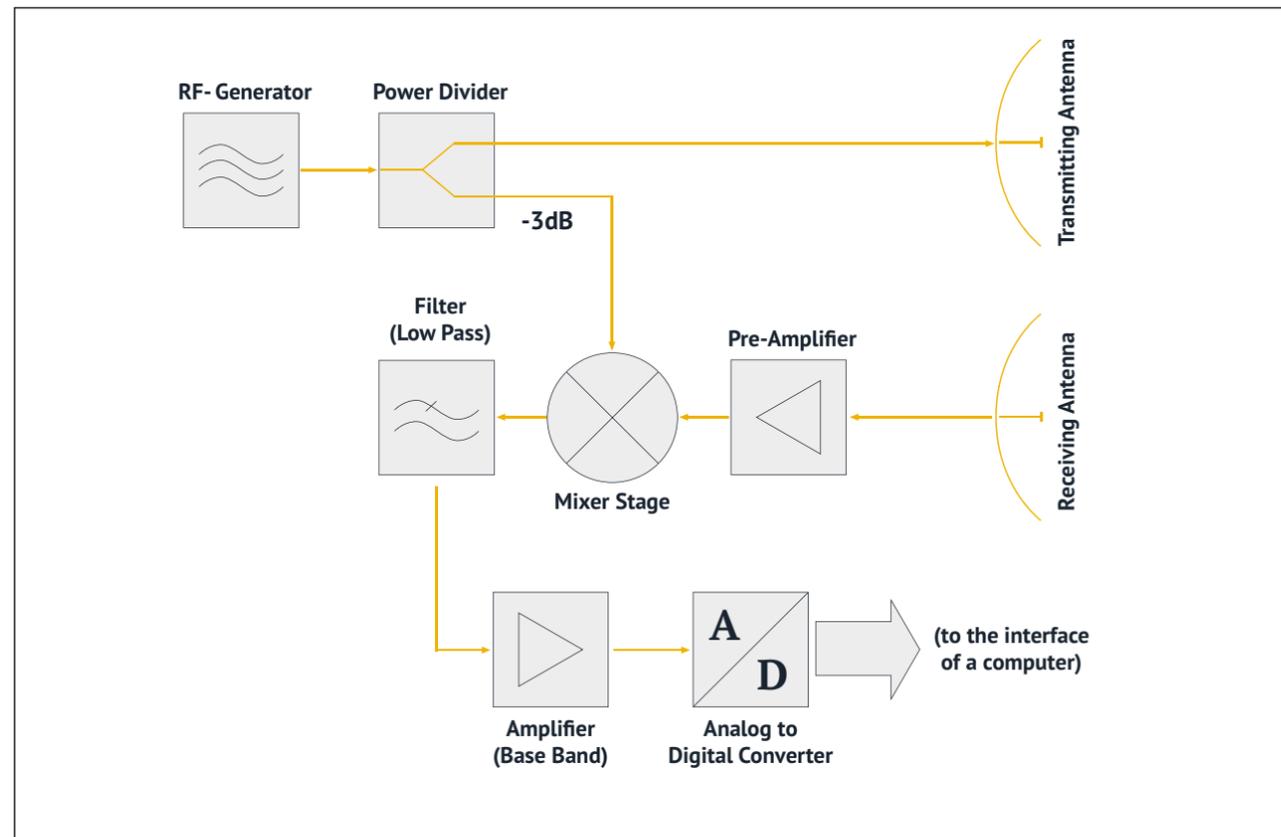
In advanced driver-assistance systems, a combination of radar types is utilized for optimal performance. Long-range radar (LRR) excels in detecting objects up to 250 meters away. Medium-range radar (MRR) functions effectively within a 1-60 meter radius, while short-range radar (SRR) operates best from 1-30 meters, aiding in tasks like blind-spot detection and parking assistance. Radar sensors are typically positioned on each side of a vehicle, encompassing the front, back, and sides. RADAR in autonomous vehicles operates at the frequencies of 24, 74, 77, and 79 GHz.

Two primary radar types are prevalent in these systems; impulse RADAR and Frequency - modulated continuous wave (FMCW) RADAR. In impulse RADAR, one pulse is emitted from the device and the frequency of the signal remains constant throughout the operation. In FMCW RADAR pulses are emitted continually.

Research and development in the last three years has pushed to solve many of the challenges in how autonomous vehicles navigate, interact, and adapt to ever-changing environments. Highlights of this research are outlined below.

Solid-State RADAR

Solid-State RADAR sensors employ electronically controlled components to eliminate the need for moving parts. This advancement contributes to higher reliability, durability, and longevity of RADAR sensors, making them suitable for the demanding operational conditions of AVs. Solid-State RADARs are also more compact, enabling easier integration into AV designs. Furthermore, their lower power consumption and reduced heat generation are crucial for maintaining energy efficiency in AVs.²⁷ This technology is being actively researched and implemented by companies such as Continental, Bosch, and Veoneer



Structure and physics of a RADAR. Image credit: BabakShah/Wevolver

for applications in AVs. The shift to Solid-State RADAR signifies a move towards more robust and affordable sensing solutions in the evolving landscape of autonomous driving.

4D RADAR

4D RADAR sensors build upon FMCW technology, incorporating time as the fourth dimension. This temporal information enhances the AV's ability to predict the trajectory of moving objects, providing a more comprehensive understanding of the surrounding environment.²⁸ AV companies like Waymo, Aurora, and Argo AI are exploring 4D RADAR sensors to enhance perception in autonomous vehicles. It is good to highlight that the importance of these sensors can vary based on the overall sensor fusion strategy employed by developers.

Synthetic Aperture RADAR (SAR)

Synthetic Aperture RADAR (SAR) represents an advanced RADAR technique that offers high-resolution imaging capabilities for RADAR sensors. It enables AVs to better perceive and

analyze objects, obstacles, and terrain, even in challenging weather conditions or low visibility scenarios.

SAR generates detailed images by synthesizing multiple RADAR measurements taken from different positions as the vehicle moves. This approach creates a large virtual antenna, resulting in finer resolution and improved object recognition. SAR is particularly valuable for identifying small objects, distinguishing between pedestrians and stationary obstacles, and enhancing AVs' perception in complex scenarios. Using sensor movement, it achieves precise angular resolution by creating a substantial antenna aperture. Given the sensor locations, consecutive RADAR measurements may be processed as if a single large antenna array acquired them. The figure below illustrates this principle.²⁹

Recent research by Cambridge, Volkswagen and the German Institute of Institute of Microwaves and Photonics have confirmed the idea that SAR imaging can be successfully

and routinely used for high-resolution mapping of urban environments in the near future.

Imaging radars

Imaging radar represents a specific RADAR variant capable of constructing 2D or 3D depictions of the neighboring surroundings. Between 2020 and 2023, significant advancements have been made in imaging radar technology, resulting in increased efficiency, improved capabilities, and expanded applications.

First, there has been a substantial enhancement in resolution and imaging precision in modern imaging radars. This development enables the detection of smaller objects and finer environmental details, significantly bolstering safety by improving the identification of pedestrians, cyclists, and obstacles.

Additionally, imaging radars have expanded their capabilities by incorporating multi-mode functionality, including weather-penetrating RADAR

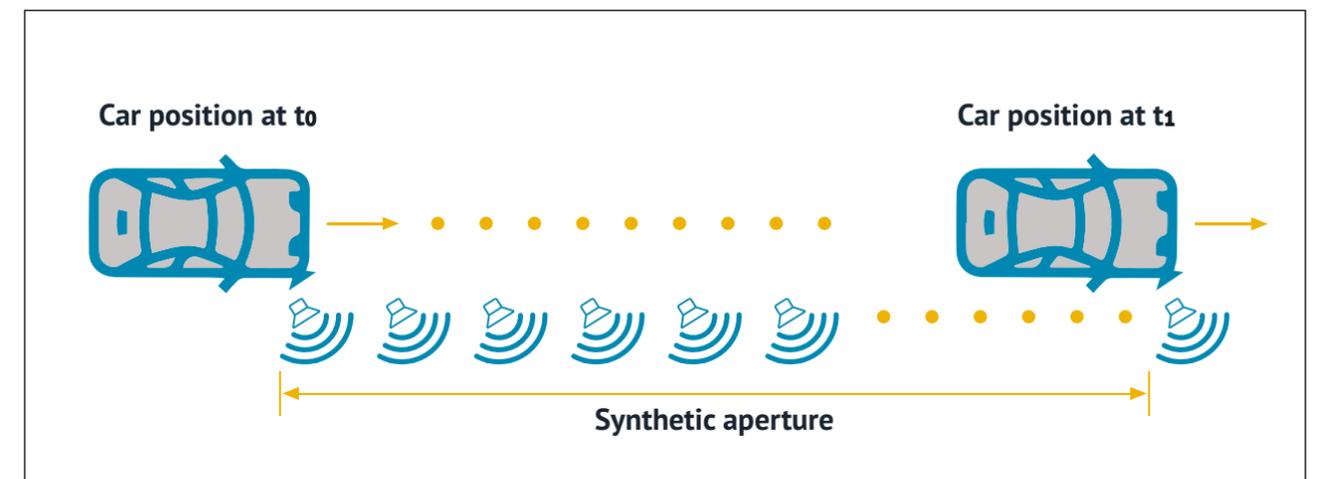


Illustration of a synthetic aperture created from consecutive measurements of a moving RADAR. Image credit:



Imaging radar can differentiate between cars, pedestrians and other objects. Image credit: NXP

modes. These modes enable the RADAR to operate effectively even in challenging weather conditions such as heavy rain, snow, or fog.

Furthermore, imaging radars are increasingly integrated with complementary sensors like LiDAR, cameras, and ultrasonic sensors to enhance perception accuracy. This sensor fusion approach facilitates a comprehensive understanding of the surrounding environment and offers redundancy during sensor failures.

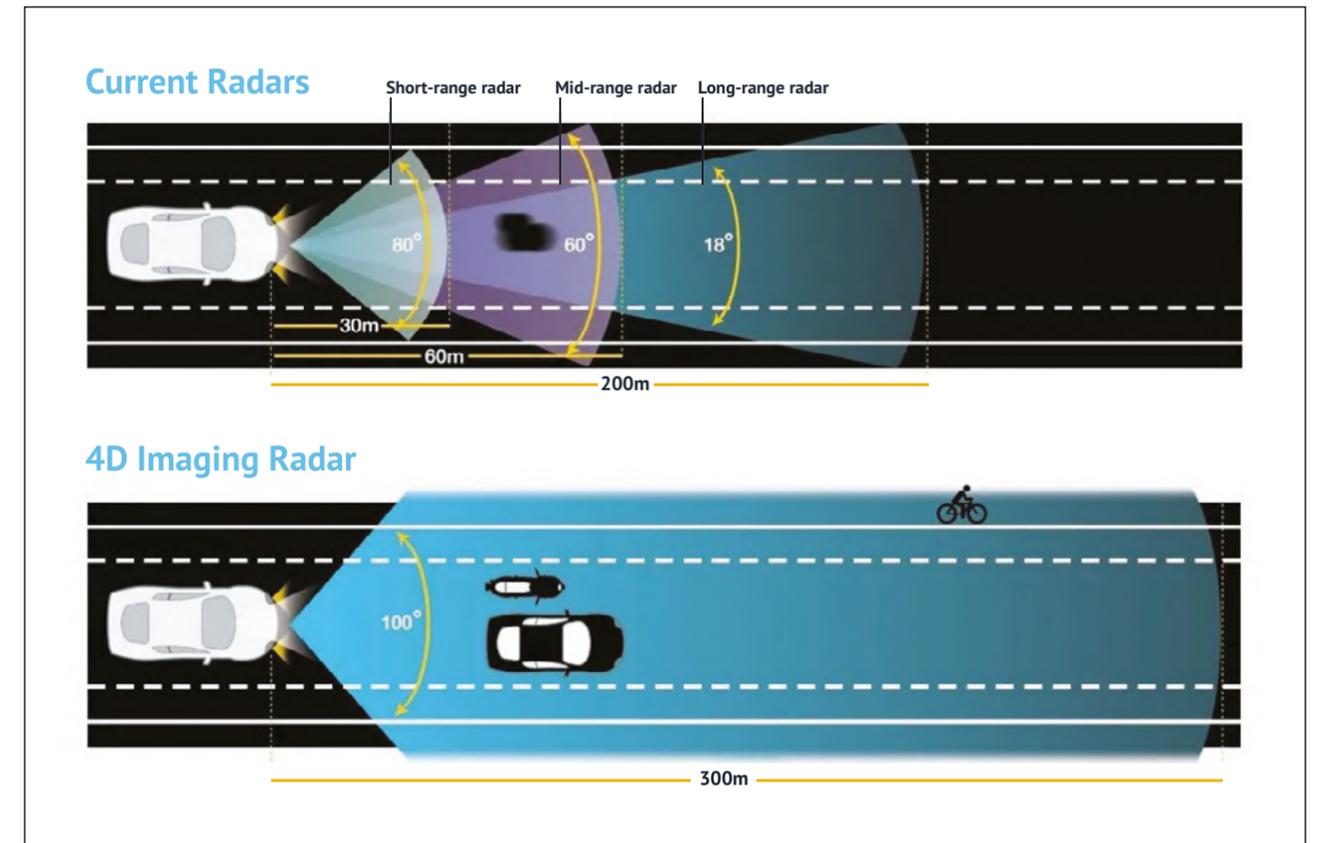
Finally, imaging radars have benefited from advancements in signal processing algorithms, which now enable them to filter out noise, distinguish between various object types, and predict the behavior of detected entities. These advancements contribute significantly to improved decision-making by the autonomous vehicle's control system, enhancing overall safety and performance.

4D RADAR

While traditional imaging radar systems construct 2D or 3D depictions of the surroundings, 4D imaging radars utilize echolocation and the time-of-flight principle to create a 3D representation of the surroundings, with time as the fourth dimension. This technique also provides information about the speed of approaching or retreating vehicles. These RADARs have successfully addressed the primary resolution challenge that conventional RADARs face – their resolution is significantly lower than cameras and LiDARs.

4D imaging radars excel at detecting objects both vertically and horizontally, enabling high-resolution object classification. This advancement enhances the RADAR system's ability to determine the vehicle's location independently. 4D imaging radars are not yet a standard in widespread use across all OEMs but it is a promising tendency. The adoption of radar

technologies varies among automotive manufacturers, which we touch on later in the Tech Stack chapter.



Comparison between current front imaging radars (coverage range from 18° to 80°) and 4D imaging radars (100° coverage range). Image credit: Future Bridge

Millimeter Wave RADARs

Research from both the US and Japan group indicates that the millimeter wave RADAR has significant potential for AVs beyond its current use in parking assist. Millimeter-wave radar offers a cost-effective alternative to LiDAR, cameras, and optical sensors, primarily because its composition is limited to an integrated circuit (IC) and printed antennas, reducing its overall expense. Additionally, this type of radar demonstrates superior performance in challenging weather conditions like fog and rain, where traditional camera systems might falter. It also excels in

detecting non-line-of-sight targets, such as those on curved road sections, making it a more reliable option in complex driving scenarios.^{30 31} Continental, ZF, Bosch, Hella, Aptiv, Denso, Nidec Elesys, Valeo, Veoneer, and Hitachi are all developing Millimeter Wave RADARs for use in high level autonomy vehicles.

Companies Developing RADAR Technologies for AVs

Below we outline companies leading the charge in the development of

cutting-edge RADAR technologies tailored specifically for autonomous vehicles.

NVIDIA NVRadarNet

NVIDIA NVRadarNet enhances traditional RADAR processing methods for object detection by incorporating a DNN approach. While classical RADAR processing can identify moving vehicles effectively, it struggles with stationary objects, often misclassifying them. The solution involved training a DNN using data from RADAR sensors to detect both moving and stationary objects and differentiate between various stationary obstacles.

“The DNNs, the deep neural networks, are becoming more and more complex. We have the ability to not just detect a pedestrian, but to detect a distracted pedestrian.”

Danny Shapiro, VP of Automotive at NVIDIA

To address sparse RADAR data, ground truth labels were transferred from corresponding LiDAR datasets, allowing the DNN to learn not only object detection but also their 3D shapes, dimensions, and orientations. The integration of the RADAR DNN with classical RADAR processing improved obstacle perception, aiding AVs in making better driving decisions, even in complex scenarios, and offering redundancy to camera-based obstacle detection.³²

Navtech

Navtech RADAR offers a robust sensor solution for AVs, ensuring performance in adverse conditions where other sensors might falter. The high-resolution, 360°, long-range RADAR excels in adverse weather and environmental challenges, providing an extensive and accurate view of its surroundings.

In 2021, this technology was chosen by Örebro University as a key sensor for groundbreaking AV research with

a special focus on the harshest of conditions for operating faultlessly in dust, dirt and when environmental visibility is low. This RADAR’s application extends to test routes and behavior analysis of both autonomous and regular vehicles, further solidifying its role in advancing autonomous technology.³³

NXP

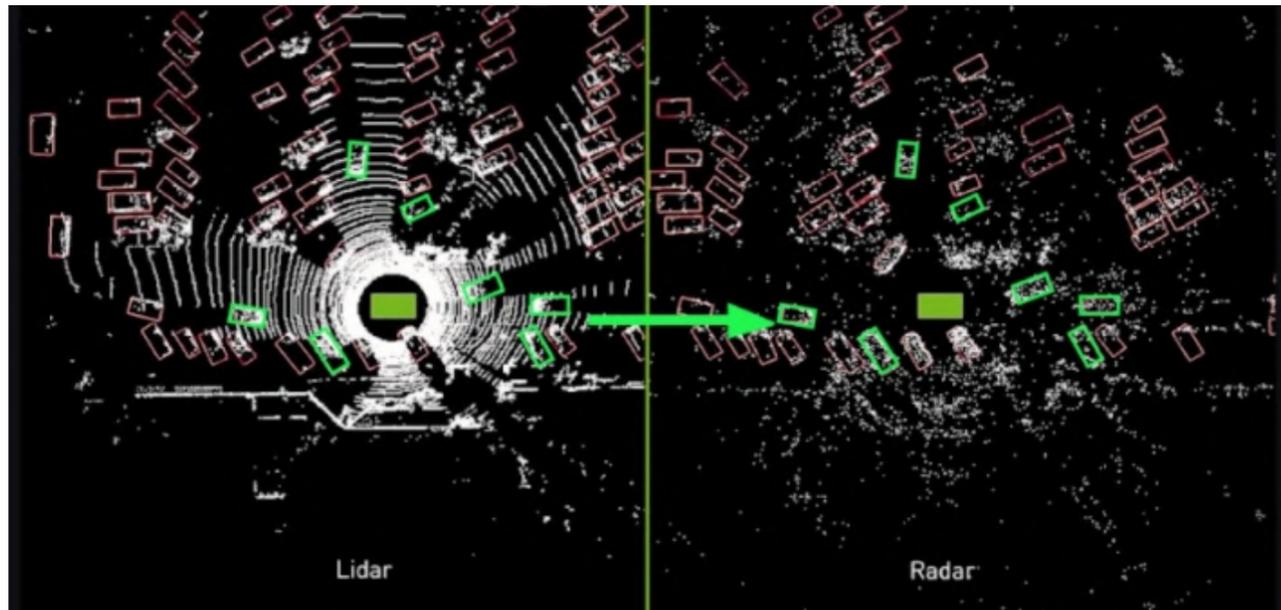
In January 2023, NXP released a new industry-first 28nm RFCMOS radar

one-chip IC family for next generation autonomous driving systems, enabling the long range detection of objects and separation of small objects next to larger ones. This technology offers faster signal processing and allows for the implementation of 4D imaging radar capabilities in vehicles, particularly for levels of automation like L2+ and higher. These developments provide a cost-effective solution for original equipment manufacturers to integrate advanced RADAR systems into their vehicles. In addition to the RADAR processor and transceivers, NXP also offers essential peripherals, including safe power management and in-vehicle network components, to create a complete RADAR node system.³⁴

Vayyar

In 2021, Vayyar, developed a production-ready RADAR-on-Chip (RoC) platform. The platform offers a single multifunctional chip capable of replacing multiple traditional one-function sensors, reducing complexity for in-cabin and AV applications. The RoC features up to 48 transceivers, an internal DSP, and an MCU for real-time signal processing, providing all-weather effectiveness and the ability to see through objects.

This single-chip solution can replace over a dozen sensors, eliminating the need for expensive LiDAR and cameras. Vayyar’s RoC offers a wide range of applications, from intruder alerts to enhanced seat belt reminders, catering to the increasing sensor density in modern vehicles while delivering uncompromising safety.^{35,36}



Example of propagating bounding box labels for cars from the LiDAR data domain into the RADAR data domain. Image credit: NVIDIA

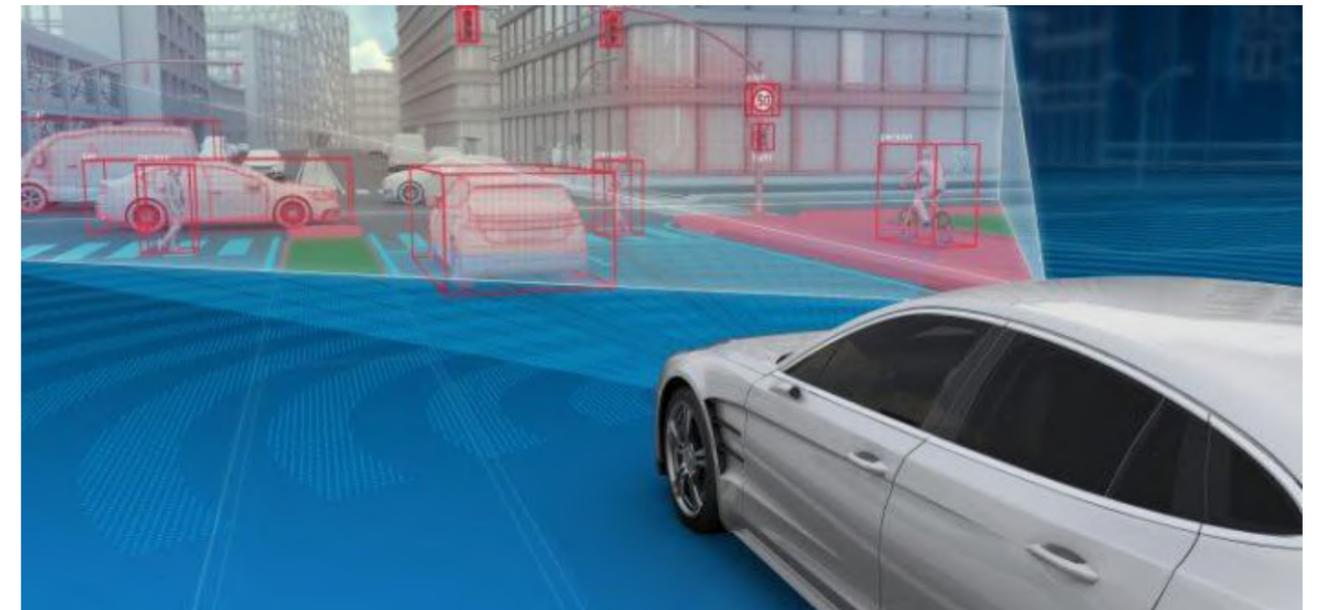


Illustration of ZF’s 4D imaging radar employed on SAIC’s R-series vehicle. Image credit: ZF

SPONSOR INTERVIEW



Misha Govshteyn, the CEO of MacroFab,
Brenden Duncombe, the Director of Customer Engineering

The Role of PCBs in Shaping Autonomous Vehicle Development

Can you both explain your roles and what MacroFab is?

Misha Govshteyn: Yeah, of course. My name is Misha and I'm the CEO of MacroFab. I've been here for about five years.

Brenden Duncombe: My name is Brendan Duncombe. I'm the Director of Customer Engineering here at MacroFab and I've been here about six months.

Misha Govshteyn: MacroFab is a digital platform for electronics manufacturing, and we're powered by the world's only factory marketplace. In most cases, companies contract with individual manufacturers.

With MacroFab, it is very different. We are a platform that gives customers access to hundreds of production lines in multiple countries. So you can literally upload your design to MacroFab and we will match you with the right factory. The best part is that MacroFab is responsible for every aspect of production. You're working with us, and we deliver the product to you.

That spans everything from prototype to production, so you don't have to switch factories. You don't have to move from one supplier to another. We have customers moving from the earliest stages of prototyping to multi-million dollar orders, all on the same platform, working with MacroFab exclusively.

So somebody like Brenden would be leading the charge with them. They may be working in different factories, multiple factories, and in parallel, but they are always working with the same team.

Thanks for the introduction. What is PCB prototyping?

Brenden Duncombe: Yeah, I can start here. In PCB prototyping, electrical engineers or hardware designers often begin with dev kits on their desks or start with an idea.

As they move through the prototyping into the production process, at a certain point, they'll need to get their design actually on a fully integrated PCB for testing or design validation. And there will usually be many stages of that. Frequently, as you go through the process, you will learn things from the early ones.

You may do one just for electrical design, then you will do another prototype where you're confirming that it fits in your mechanical enclosure, or you may have to produce some prototypes for RF testing. So, for each one of those stages, you will need to get a very low volume of PCBs made to do integration, testing, and validation.

Misha Govshteyn: The design process for all of the world's products is now computerized. Some CAD products help you design mechanical parts, even for woodworking, right?

There are digital products. So you're sitting in your computing environment. You can do 3D renderings of things – the same thing for electronics. So, a lot of the design process happens in people's heads. It occurs in computing environments where you can do simulations.

But at some point, the simulation is not enough. So you've got to take that virtual design where you can see what your circuit board looks like and make assumptions about how it works. And you have to produce a functional prototype. So you can plug it into other auxiliary devices connected to other parts.

Physical products require physical prototypes. So, usually, the design process is iterative. You design something, build a physical prototype, and see how it works, but it usually works differently than you expect.

So you have to build multiple iterations of it, and really, the faster you can go from the digital version of it to the physical version of it and iterate quickly, the more you're compressing time for design iterations. Engineering time is costly, and this goes for every stage of production.

We're talking about prototyping right now. Switching factories and waiting for things to happen in factories is the most expensive thing in the world.

You change the design, and now you have to wait a long time for the factory to reflect that design; that is an actual cost, and that's part of what MacroFab is compressing because everything happens on the same platform.

It doesn't matter which factory you need. We have hundreds of production lines to prototype and eventually build a production.

What's unique about MacroFab's approach?

Misha Govshteyn: We're the first and only platform connecting customers to hundreds of production lines. Usually, all of this is people work.

What happens when an engineer needs a factory? Either an engineer gets on a plane, or their supply chain gets on a plane, and starts traveling halfway around the world to find out which factories are good and which are bad.

You can't tell when you walk into a factory. You can even hear people say things like this factory had the right smell. That's usually a sign that they have yet to determine whether it is a good factory. Factories are data. Factories are output.

We're the only way to aggregate many factories in one place and understand what they are good at building, what they are bad at building, and what kind of equipment they have.

Can they even notionally build the right product, given the design parameters? Some factories have old equipment, and some factories have modern equipment. Humans aren't fast enough to understand all of this, but our software is much faster and does it algorithmically, so how we match up customers and factories is much faster than everybody else. And one big realization we made is that none of that works without humans at the end of the day.

So we have humans in a loop, and guys like Brenden actually do travel to factories. But Brenden knows precisely what he's looking for when he walks into one. So I think we take a lot of the heavy lifting from customers, irrespective of how difficult their job is or how complex the requirements. I had a very well-known automaker that at one point reached out to us and said, "Hey, I have this unusual PCB. It is a 30 by 5 form factor that doesn't fit into most factory machines. Can you build this?" Out of our hundreds of production lines, we had three that could create that particular board, which would have been a months-long exercise for a traditional supply chain team.

With our software, that happens very quickly. Again, we're the only business out there that operates this way. Usually, you work with factories individually, but most importantly, it is not just a thing that matches up customers and factories. We are the ones responsible for production. We are the ones producing it in this factory network. We have design engineers, we have manufacturing engineers, we have quality engineers, and ultimately we are the ones delivering products to the customer. It is the all-in model for churning and manufacturing into a cloud-like service.

Brenden Duncombe: Yeah, and I would say also one of the more unique aspects is that typically in this process, when you move from prototyping to production, most customers are used to, working with a prototyping shop, and then they have to learn all the same lessons over again when they move to production.

They have to get prototypes from the production house to make sure that they know how to build it correctly, even though they already have prototypes from their prototyping house.

And it is very unique that we handle both aspects of that. You can stay with us for any volume of PCB, and we move through your production lifecycle with you.

Expanding on, obviously one of your USPs is that customers can go from prototype to production without sharing files with factories or people needing to find the right supplier. Could you explain that process in a little bit more detail and some of the technology for example, do you use a lot of AI with this?

Misha Govshteyn: Well, to be clear, our customers do share files with us, but we are one of the most secure platforms for doing so. My background is outside of manufacturing. I come from the cybersecurity world. Brenden comes from the electronics world. So, data privacy and cyber security are the main domains. But at the end of the day, you're sharing your design files with one party.

That's MacroFab. We are extracting only the relevant information that the factories need to decide whether they can build it and sharing just that abstract with them. That's in contrast with what usually happens in a supply chain world. Coming from a cybersecurity background, I know how blind we are to what happens in a supply chain universe.

But in reality, no thought happens about what your partners need to see and what they don't. What you get many times is a multi-gigabyte package of everything. You get giant design files.

They blast this to every supplier for price discovery. They're just trying to figure out who can build this product and do it at the lowest possible price. The privacy implications of that are immense. So we always get asked: "What is my risk?" What you're doing now is incredibly risky.

You're sending files to all sorts of factories. Some of these factories may not even be real. With us, it is a very different story. You send it to MacroFab. Take that digital package. Share only the relevant information with factories that need to see it.

So, software determines who gets to see this information. We use many algorithms and a lot of machine learning to do that. But ultimately, it is not just algorithms. Many times, it is data classification and knowing who should see something.

Brenden Duncombe: Commonly, we will see customers share data that is optional for quote. You will see firmware files.

You will see things about their assembly. All of that, we strip out and only share the stuff that's required to manufacture the piece that they're quoting.

Misha Govshteyn: But the current supply chain and data privacy state is terrible. Right now, by definition, I was blown away when I saw what we received from customers as quote requests.

It is a massive amount of unnecessary information. As Brenden said, sometimes they'll package source code with it. There are better reasons to share your most intimate secrets with your suppliers than price discovery.

And who are your customers and what industries do you work in?

Misha Govshteyn: We are most dominant, I would say, in the industrial space. So that's probably our biggest segment. We have a lot of automotive companies that work with us, and we have done much work with autonomous trucking companies.

And especially at the earliest stages of design, which is a high-tech, very iterative industry, our ability to turn around prototypes very quickly is important. Many times, these companies are tech startups. So the electronics team want to modulate how they work and how the software team works.

Software teams these days use concepts like continuous deployment and rapid iteration. So they match their cadence. Because often, it is not just about building a PCB prototype; firmware gets burned onto it.

So, the software team has to be in lockstep with it and vice versa. If your software team executes very quickly, but your hardware team is slowing them down, everything slows down. And we're talking about some of the most expensive resources in the business slowing down across the board. We work with many startups, many drones, and many robotics companies.

Oil and gas is a big field for us. We're in Texas, so that's natural. A lot of innovation and digitization happens in oil and gas.

We don't do many consumer electronics. I think of that as almost an entirely different industry. I think building one type of product for millions and millions of people is fundamentally a different job than making something like an automotive product where each car has, on average, something like 85 circuit boards.

And I think that number is growing. There's an immense amount of chips in cars. There's a tremendous number of PCBs. Even mundane things like you turn on your blinkers. There are PCBs involved in that. Even traditional cars, much less autonomous cars.

How important are PCBs in autonomous cars?

Misha Govshteyn: I'll defer most of the answer to Brenden, but when you really think about what autonomous cars are built from, it is a lot of very high-powered computing units. Some of the automotive computing units are as powerful as crypto crunching devices and they have many sensors.

None of these things talk to each other without electronics. Obviously, PCBs are where you mount a lot of this infrastructure, so it is probably better for Brenden to explain it in more detail, but it simply doesn't work without PCBs.

Brenden Duncombe: At the end of the day, nothing works without circuit boards connecting it all together. As Misha said, the number of PCBs in cars is skyrocketing.

The amount of information in cars is skyrocketing, and many autonomous vehicles have moved to higher bandwidth interconnects. Every car used to be a CAN bus, and now people are laying down automotive ethernet and things like that in order to increase bandwidth in cars. And that's in large part due to the number of sensors streaming video from every corner of the car. LiDAR sensors, for instance, require sensor computing. Like mainframes in your car or processing in your car, whatever is doing the decision-making, your AI computes modules. All of that is getting fed back in every single one, especially the sheer amount of distributed sensing on the car. All of that either requires the support circuitry on the sensor or computer in order to make that usable for decision-making.

What does MacroFab's approach mean to the way you manufacture and design PCBs and the rollout of autonomous cars? Does it mean we can get to autonomous cars more quickly because of your process?

Misha Govshteyn: I think for the traditional automakers, the conventional manufacturing approaches are fine. They move much slower. When you think about traditional automakers, controlled releases are really what they're working against. And I've worked with several people in software from the auto industry.

They're usually frustrated by how slowly things iterate and change on cars. But every one of those automakers has crossed over into the digital software-driven world in the last couple of years.

Toyota is the largest, and it has a separate auto company that started specifically for that purpose. The same thing is happening with hardware teams as well. A lot of the production factories are still heavily controlled.

A lot of the prototyping it does is actually happening very rapidly, and it needs a software-enabled, digitized approach to it. By the way, as a data point, how many compa-

nies out there can receive and give you a price quote on your electronic design over a set of API calls?

There's only one, and that's us right now. So we're the only company out there that's truly software-enabled for electronics manufacturing. And that means that if automakers want to move faster, this platform is most aligned with that motion.

Brenden Duncombe: I think it is very clear that now the software is moving a lot more quickly than the hardware is. To keep up with that, especially when it comes to the sensing capability and setting the compute capability (such as quicker turnaround times and getting that performance to validate your models against your machine learning models, your AI models), it is critical to evaluate the performance of those.

As those models get better and better, whether they can go with lower resolution sensors or find out they need higher resolution, all of that change to what is required to feed those models requires faster prototyping.

What's your opinion on when we'll see mass adoption and rollout of autonomous vehicles?

Misha Govshteyn: We're certainly seeing a rollout now. Major rollout is happening in Texas, Arizona, and California. As for now mass adoption; people have been wrong about that forecast for so many years.

I'm hesitant to put a number out there, but I think within five years or so. I actually don't think there's going to be a switch that makes everything autonomous. We are going to see transportation segments moved towards autonomous cars in a major way.

So I think a certain portion of driving will be done by autonomous vehicles, probably about a third or so in the next five to seven years. That's my guess.

Brenden Duncombe: I'm also hesitant to make predictions on something that has been so famously incorrectly predicted before.

Similarly, we're seeing a lot of rollouts already. A lot of these have been in limited areas or with certain speed and streets and so on.

As we move forward, I'd like to see if there has been more discussion about the type of infrastructure to support autonomous cars. In addition, I'd like to see if more adoption of better-connected infrastructure helps ease the adoption.

And so, as we move into a world where we're seeing the rollout before getting more comfortable, it is okay to make an investment in some infrastructure to help support this and make the adoption easier. That will certainly help speed things along.

Obviously regulations change and technology improves all the time, but what are some of the other big challenges that will affect the rollout of autonomous vehicles in the future?

Misha Govshteyn: It needs to be regulatory, first and foremost. Cruise just had to suspend its operations in Texas. You know, it is all related to technology. Meeting the real world is full of conditions that even the best software in the world can't necessarily predict. And sometimes that means the irrationality of courts and law enforcement. So, in this case, Cruise didn't even cause the accident. It was a human driver that caused the accident. But Cruise was involved as this kind of secondary actor, and they still had to deal with the outcome.

I'm certainly not an expert in the evolution of automotive products, but autonomous vehicles are going through the same journey as when cars originally became dominant products. Eventually, regulators stepped in and started to slow things down. That's probably the biggest variable. Ultimately, regulatory controls are the biggest thing standing in their way.

Ironically, I'm not necessarily down on regulatory controls. I think there is at least one area, for example, where they could be immensely helpful. For example, right now there's no regulation out there for where you send your intellectual property and how much of it is to send to which countries.

So we treat other countries as just a place to get lower costs when we should treat other countries at the very least as competitors and, in some cases, adversaries. More regulatory controls in that domain would actually be a net positive. Right now cost is the thing that supply chains care about most.

I think in the future they will all move faster if they stay closer to home. Working with companies like MacroFab, they can match their speed requirements. From experience, often in order to do the most secure thing you have to be forced to do it by regulatory controls.

So, I think regulation is obviously a double-edged sword.

Brenden Duncombe: I think regulation is the main thing. I also think that when we start talking about mixed-use, it is easy to envision a world where every car's autonomous, and so they all work together just fine.

But I think the public response is also part of it, right? Autonomous cars are a massive change and they drive exactly the same way humans do it, so that will take some getting used to.

I think there's a lot of human adoption needed with being on the road and your usage patterns, but also driving that adoption. Even if the regulators approve it, there can also

be a lot of pushback from other drivers that could also come to issue. So it is both sides of the market. Other users of the same infrastructure, need to be prepared to share that.

Misha Govshteyn: To extend what Brenden said, it'll also follow the typical hype curve. Right now, there's a lot of excitement about it. Everybody wants things to happen smoothly and very quickly. And that's almost never the way technologies get adopted. We've mentioned it, but this is the point that we reiterate. Right now, the hardware world is the long pole attempt.

It is one of the things that takes the longest. And perceived constraints by the supply chain drive a lot of it. People throw up their hands and say, I don't really know how to build this any faster. I know the software is ready, and it is already very quick.

But my hardware cannot be. The answer to that is it can be. It can be with MacroFab. A lot of it comes down to whether supply chain teams are able to move quicker, just as fast as software teams, and just as fast as hardware teams want to move. That is an executive change. Only a top-down message can really break through to that because until you change the requirements for supply chain teams and say speed is more important than cost, there will always be this mismatch between how quickly the business wants to go and what the supply chain team is optimizing for.

I know how these people get their bonuses, which is the most important thing in the world, and it is still not based on the speed of iteration, it is not based on how quickly they turn prototypes or anything else around, it is all about the bottom line at this point and ultimately there is a big mismatch between the expectations and reality of supply chain.

Brenden Duncombe: Similarly, the software world has adopted CICD and continuous integration and continuous deployment in order to tackle this fast iteration. It is very common now. Anyone who starts a project, most of the time it is a software project. The first thing you do is you set up your deployment chain, right?

You have all of that built-in. Similarly, the electronic world and hardware world can keep up with that. More engineers should feel comfortable iterating hardware more quickly, deploying the exact same technology that they use for software, hardware, and infrastructure for testing and getting away from this mindset.

They're like, "well, we still have to support this legacy hardware forever. We made a mistake in the prototype, and we patch it with software" tech debt the years.

That mindset needs to change a little bit in these areas, and industries that are moving more quickly and iterating can use MacroFab for that support.

Misha Govshteyn: And supply chain is one of the blockers for that because even the

engineers that want to do that eventually get told that sounds great as long as it integrates with our ERP.

That is maybe the most expensive requirement. With MacroFab when they want to move fast, we can enable that with our APIs.

The supply chain team has to be part of that answer. You can't have an agile enterprise and a traditional supply chain team. Those two things are incompatible.

Ultrasonic Sensors

An ultrasonic sensor is an electronic device that measures the distance of a target object by emitting ultrasonic sound waves, and converts the reflected sound into an electrical signal. Within autonomous vehicles, they are most commonly employed to create Intelligent Parking Assist Systems (IPAS) which aid vehicles that in parking maneuvers by providing real-time distance and object detection information to the vehicle's control system. From an innovation perspective, ultrasound technology is not known for frequent breakthroughs. Nevertheless, two recent technical solutions in the field of AVs deserve special attention.

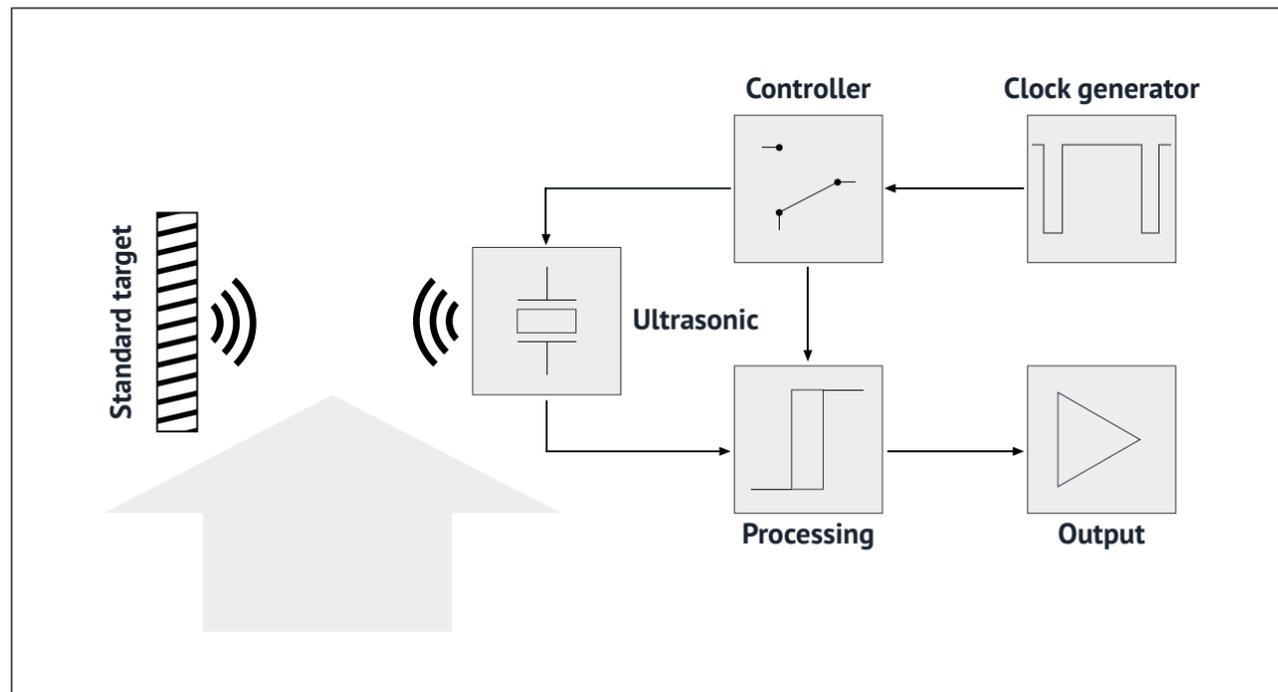
In 2023, MEMS Ultrasonic Sensor Solution introduced an Intelligent Cabin Child Presence Detection system, crucial for child safety in vehicles. It utilizes various sensors to detect children inside a car and alerts the driver. The MEMS ultrasonic sensor module has compact dimensions, measuring 30 x 20 x 5mm, significantly smaller than both open ultrasonic and millimeter-wave RADAR modules.

This MEMS ultrasonic Child Presence Detection solution boasts a detection distance of over 1m and a field of view reaching 180° (±90°), ensuring comprehensive coverage and precise monitoring for all cabin positions. Notably, the latest Euro NCAP standards suggest that MEMS ultrasonic sensing could dominate Child Presence

Detection systems due to its efficient vital sign detection, extensive sensing range, compact size, and discreet installation. NCAP has now included Child Presence Detection in its testing criteria.

Also, in 2023, Murata unveiled a new water-resistant ultrasonic sensor designed for self-driving cars, known as the MA48CF15-7N. This sensor is highly sensitive, responds quickly, and is enclosed in a sealed case to protect it from liquids. As cars become more autonomous, the demand for precise short to medium-range sensors to detect objects is growing. The MA48CF15-7N operates by emitting ultrasonic waves and measuring the time it takes for them to bounce back, determining the presence and

distance of nearby objects. This sensor can detect objects as close as 15cm and as far away as 550cm, covering a wide area with a 120° by 60° angle. Notably, the sensor's capacitance is 1100pF±10% at 1kHz, ensuring consistent performance without the need for frequent adjustments. Operating at a resonant frequency of 48.2±1.0kHz and with a quality factor (Q value) of 35±10, it delivers reliable performance across various temperatures. These specifications are notably more precise than previous models from Murata, with a 50% reduction in variability, ensuring consistent performance across different units.



Structure of an ultrasonic sensor. Image credit: Medium - Babak Shahian Jahromi (Adapted by Wevolver)



Location of Continental ultrasonic parking sensor. Image credit: Continental

Nexperia Engineering Team

Exploring the Future of High-Performance Computing in Autonomous Vehicles

The automotive industry is grappling with the need to develop hardware that is not only reliable and efficient but also compact enough to fit within the confines of a vehicle. This challenge is amplified by the increasing demands of Advanced Driver-Assistance Systems (ADAS) in autonomous vehicles, which require immense computational resources to process data from an array of sensors and cameras in real-time.

The shift towards centralized ADAS architectures marks a significant departure from traditional vehicle design. These systems resemble mid-range server architectures, equipped with dedicated GPUs optimized for complex algorithms and self-learning capabilities. The processing power required for these systems is immense, necessitating the use of multiple high-power microchips. This evolution raises critical questions about the reliability, safety, and energy consumption of these computing units, especially given their crucial role in autonomous driving.

An intriguing aspect of this technological evolution is the continued relevance of discrete components in automotive systems. Despite advancements in integrated circuits, discrete components like transistors, MOSFETs, and diodes remain vital due to their flexibility, reliability, and cost-effectiveness. This persistence underscores the dynamic nature of automotive semiconductor technology and its critical role in shaping the future of autonomous vehicles.

In this brief interview below we heard from Nexperia engineers as they discuss how the increasing demand for computational power in vehicles is reshaping automotive design, the challenges in ensuring system safety and reliability, and the broader impact of these changes on the semiconductor industry.

1. What are the most recent trends in terms of incorporating new electronic devices into the vehicle and manufacturing processes?

The automotive industry is undergoing a major transformation, with electronics playing an increasingly important role. Recent trends include electrification, connectivity, and autonomous driving. As the automotive industry shifts towards electric and hybrid

vehicles, there is a growing demand for high power and wide-bandgap electronics solutions such as Silicon, SiC and GaN MOSFETs, IGBTs, diodes, and other semiconductor devices capable of efficiently managing and controlling electric power. Nexperia is at the forefront of this trend, developing innovative semiconductor solutions specifically tailored for electric vehicle applications, enabling higher efficiency, increased power density, and improved thermal management in automotive electronics.

2. How are vectors such as electrification, connectivity and autonomous vehicle developments influencing the role of electronics in automotive?

Electrification, connectivity, and autonomous vehicle developments greatly influence the role of electronics in automotive applications. Electrified vehicles demand more semiconductor content, driving the need for advanced components. Connectivity requires seamless vehicle-infrastructure communication, while autonomous vehicles rely on complex sensor systems. All three vectors are interconnected, with electrified vehicles offering better options for advanced electronics. Components like camera systems, radar systems, and larger displays rely on electronics. Overall, these vectors amplify the role of electronics in the automotive industry, necessitating advancements in electronic components and systems to support powertrain control, communication capabilities, and autonomous functionalities.

3. How can electronics contribute to areas such as sustainability and efficient energy management?

Electronics play a vital role in enabling sustainability and efficient energy management. At Nexperia, our focus on developing better power semiconductors enables more efficient cars and applications. By minimizing power losses and enhancing power conversion efficiency, our semiconductors significantly contribute to lower energy consumption, reduced carbon emissions, and extended range in electric vehicles. Efficient power electronics also support renewable energy systems, smart grids, and energy-efficient industrial applications. Through our semiconductor solutions, we strive to enable greener technologies, enhance energy efficiency, and drive the transition towards a more sustainable future.

4. How is your company working on innovating new electronic solutions, either for the vehicle or for your manufacturing processes?

Every new car today already has approximately 600 Nexperia devices, and while our products are very small, the combined effort can have an impact on the efficiency and performance. Thus, we are working on innovating new electronic solutions for both vehicles and manufacturing processes. And while we continuously innovate the "workhorse" silicon, we are also developing leading-edge wide bandgap devices. These silicon carbide (SiC) and gallium nitride (GaN) semiconductors offer higher efficiency and performance compared to traditional silicon-based devices. By incorporating

wide bandgap devices, we enhance power efficiency and improve system performance, reduce size and weight of systems, extend the range of electric vehicles and reduce carbon emissions. We also prioritize the development of more efficient power semiconductors that minimize power losses and improve thermal performance. This ensures reliable and long-lasting electronic systems in vehicles, supporting their overall efficiency and reliability. Our compact and space-efficient package designs optimize PCB space, benefiting car manufacturing processes. By utilizing better-performing power semiconductors, we contribute to increased mileage for car batteries, promoting sustainable transportation. Nexperia remains dedicated to pushing innovation boundaries, focusing on wide bandgap devices, efficient power semiconductors, thermal performance, and space optimization to advance electronic solutions for the automotive industry.

Thinking and Learning

Autonomous cars employ advanced algorithms, machine learning, and artificial intelligence to „think” and „learn.” They gather data from various sensors like cameras, radar, and LiDAR, and then process and interpret this data to understand their environment. Machine learning enables these vehicles to improve over time, adapting to new situations and optimizing their responses.

The decision-making process is real-time, with the onboard computer systems controlling navigation and obstacle avoidance. Additionally, network connectivity and cloud computing play a role, allowing the vehicles

to access broader data and computational resources for enhanced learning and decision-making.

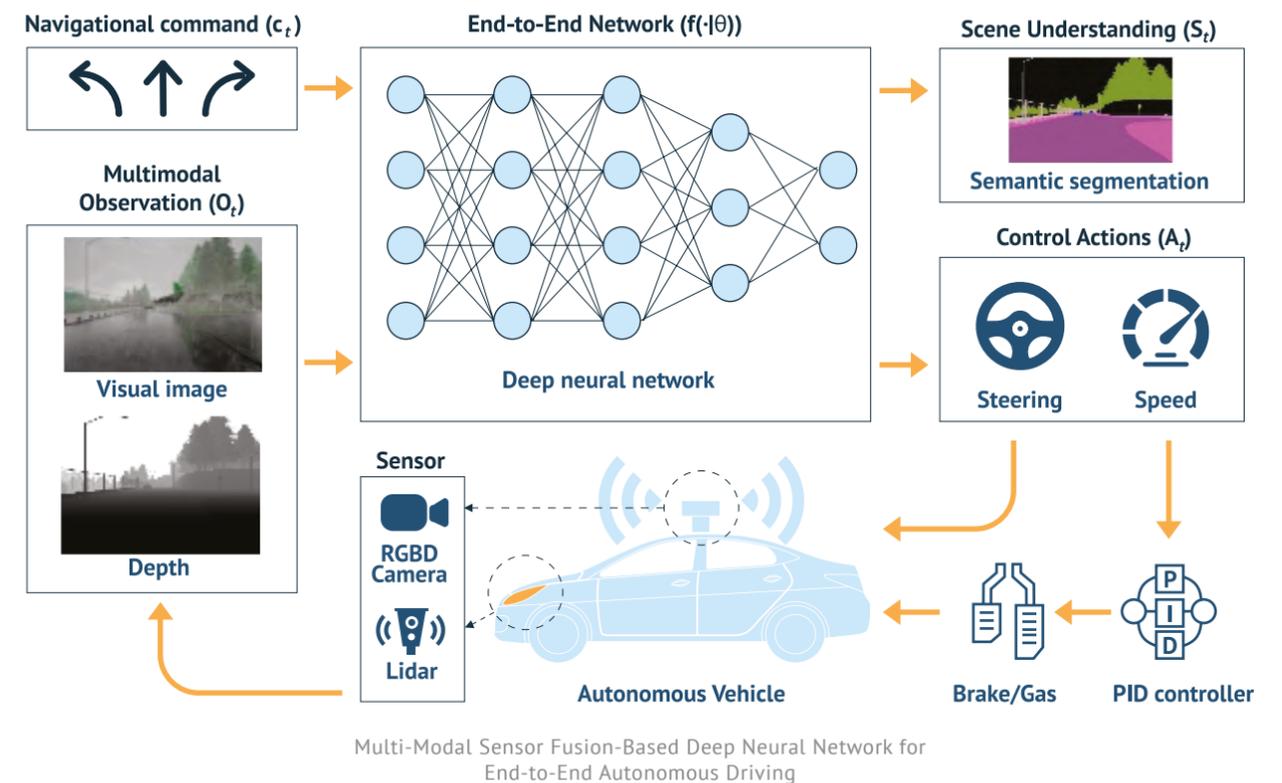
In this section we focus primarily on learning for AVs as well as the interface between machine and humans.

Frontiers of AI Learning Approaches for AVs

Multi-modal learning allows AVs to glean insights from a range of data sources, including visual inputs, RADAR data, and LiDAR readings. Over the past three years, the integration of multi-modality 3D object detection, for example, has emerged as a promising strategy to bolster the accuracy and resilience of perception tasks in autonomous driving. These advance-

ments encompass diverse methodologies, such as employing sophisticated cross-modality attention-based feature fusion, crafting more dependable homogeneous representations across distinct modalities, and formulating intricate and resilient unified frameworks. Examples range from 3D detection based on LiDAR data and camera-LiDAR fusion to the prediction of multimodal trajectories within autonomous driving systems.^{37 38}

Deep Reinforcement Learning empowers control logic to make optimal real-time decisions. This adaptability makes it particularly well-suited for the ever-shifting and uncertain circumstances inherent in AVs. In the last three years, reinforcement learning has been employed in autonomous driving to optimize controllers, refine



path planning and optimize trajectory, enhance motion planning and dynamic path planning, formulate high-level driving policies for intricate navigation challenges, and implement scenario-based policy learning for diverse scenarios. Moreover, it can also be employed for reward learning through inverse reinforcement learning from expert data, aiding in intent prediction for traffic actors like pedestrians and vehicles.³⁸⁻⁴⁰

Shift from task-specific to task-agnostic AI represents another frontier of AI learning approaches for AVs in the last 3 years. Traditional AI systems require training on millions of examples within a specific domain. For instance, an

image-recognition system needed extensive data to identify animal species. However, recent developments have led to large foundation models that can be trained on general data using self-supervised learning. These models can grasp general concepts with few examples or prompts, significantly improving their adaptability to new scenarios and improving technology performance and safety.

Innovation in generative AI technology, it's the most advanced, high-fidelity closed-loop simulator to date, crucial for enabling autonomous driving. Generative AI could be efficiently used to create highly accurate digital replicas of the real world from raw sensor

data. It can modify these replicas to simulate endless scenarios for training and testing AVs.

This includes adding or removing other vehicles, simulating emergencies, accidents, and more. This technology creates both typical and critical driving situations automatically and on a large scale. This reduces the need for real-world test driving, making autonomous driving development safer and more cost-effective. The combination of generative AI-powered simulation with an AI model tailored for physical interaction promises faster, safer, and more scalable deployment of autonomous technology worldwide.

NLP and GANs Reshaping Autonomous Driving

Natural Language Processing (NLP) enables machines to understand and generate human language, facilitating effective communication between humans and machines. The synergy between NLP and AVs has introduced novel dimensions to human-machine interaction and AV safety.

Incorporating NLP into AV software encompasses diverse methodologies. One approach involves adopting a rule-based system, entailing the creation of rules that govern the understanding of natural language commands. On the other hand, an approach involving ML can be employed, entailing a model's training on a dataset comprising natural language commands and their corresponding actions.

The choice of approach is contingent on the specific application. Rule-based systems are well-suited for simpler scenarios like controlling a toy car, whereas ML systems are better equipped to handle more complex tasks, such as orchestrating the actions of an autonomous vehicle.

The incorporation of NLP-driven human-vehicle interaction provides numerous advantages, including:

- Enhanced safety by allowing drivers and passengers to engage with the vehicle without diverting their attention from the road.
- Diverse linguistic preferences, which enable a broader user base to communicate effectively with the AV.
- Increased AV efficiency. Travelers

can leverage natural language queries to access details about their environment, which can help to plan trips more effectively.

- Personalized touch that offers tailored responses based on individual preferences and contextual understanding.

In general, NLP technology equips vehicles with the capability to process, comprehend, and respond to human language inputs, thereby creating an intuitive interface that fosters seamless interaction. The integration of NLP into AVs operates through intricate mechanisms that facilitate effective communication between passengers and the vehicle's AI system.

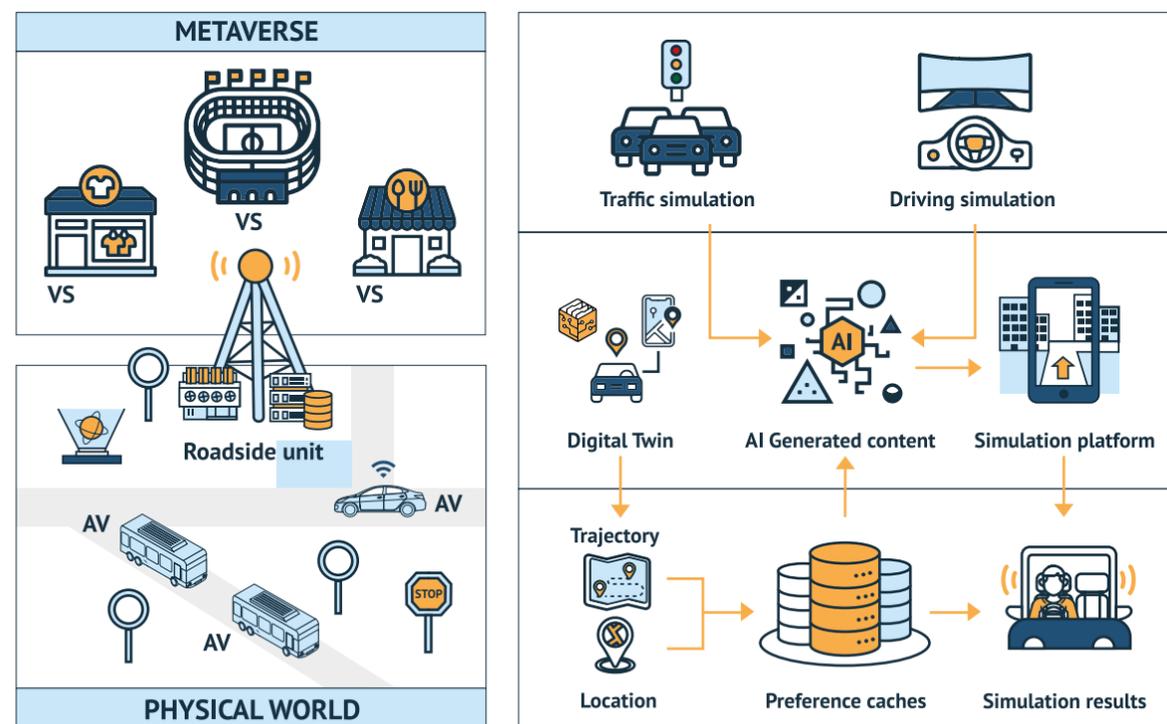
For example, Cruise employs NLP for voice commands, enhancing the user experience by understanding complex queries. The company's commitment to interactivity is reflected in the advanced NLP capabilities. Additionally, Cruise utilizes AI in its Continuous Learning Machine, automating data processes to enhance driving system accuracy and safety over time, making the vehicles more adept at handling real-world driving scenarios.

When talking about GANs, their capacity to generate highly authentic images and videos has established them as pivotal networks for cutting-edge AV development. This distinctive capability positions GANs as valuable tools for training AVs to effectively recognize various objects.

In 2020, Uber's Advanced Technologies Group (ATG) has introduced an innovative AI technique aimed at enhancing the prediction accuracy of autonomous vehicles' traffic movements. This meth-

od, applicable to Uber's own driverless technologies, utilizes a generative adversarial network named SC-GAN (scene-compliant GAN).

Unlike simpler architectures, SC-GAN incorporates high-definition maps and detection/tracking systems informed by LiDAR, radar, and camera sensors to create trajectories that adhere to scene constraints. This novel approach is expected to significantly improve the precision of predictions, addressing critical issues for autonomous vehicles, such as the ability to detect and anticipate surrounding cars' trajectories.⁴¹



VS: Virtual simulator
AV: Autonomous vehicle

Autonomous driving systems with traffic and driving simulations empowered by generative AI.

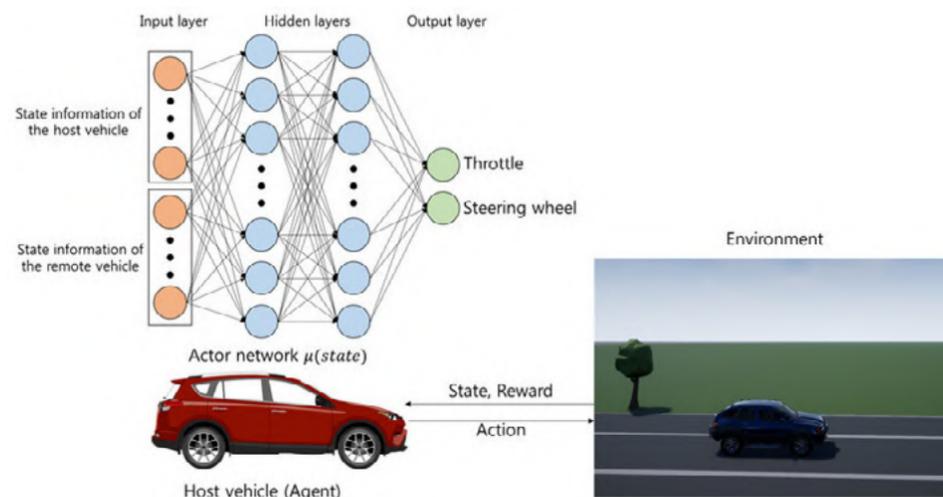
Harnessing the Power of LLMs for AV Applications

Following the release of ChatGPT there has been a surge of interest in Large Language Models (LLMs). In the context of AVs, LLMs can be seen as a more specialized version of NLP that can support more general and more interactive applications. Leveraging these characteristics, the use of LLMs is considered for a variety of AV use cases including

- Integrating language and reasoning capabilities into autonomous vehicles.
- Supporting high-level decisions through chain-of-thought.
- Implementing generative driver agent simulators that can provide, perceive and analyze complex traffic scenarios towards improving the navigation features of the AV.
- Personalizing the driver's experience based on verbal feedback from LLMs.

“The new wave of generative AI is going to play a major role in every one of those departments and the ability to create digital twins is really helping every department as well and integrating those.”

Danny Shapiro, VP of Automotive at NVIDIA



Architecture of decision-making system proposed in “Decision-Making System for Lane Change Using Deep Reinforcement Learning in Connected and Automated Driving”. Image credit: HongIl An and Jae-il Jung

Companies Developing AI Algorithms for AV Applications

Company	Headquarters	Founded	Focus Area	Technology Details
Waymo	Mountain View, CA, USA	2009	Fully autonomous driving technology	Waymo Driver: LiDAR, radar, cameras, machine learning for navigation and decision-making.
Tesla	Palo Alto, CA, USA	2003	Autopilot and Full Self-Driving (FSD) systems	Autopilot and Full Self-Driving (FSD) systems: Cameras, ultrasonic sensors, radar, neural network processing.
Cruise	San Francisco, CA, USA	2013	Self-driving car services	Self-driving car services: LiDAR, radar, cameras, integrated into electric vehicles for urban environments.
Aurora	Pittsburgh, PA, USA	2017	Self-driving technology for various applications	Aurora Driver: Sensor suite including LiDAR, radar, and cameras, for various vehicle applications.
Aptiv	Dublin, Ireland	1994	Automated driving technology	Automated driving technology: Advanced safety systems, vehicle connectivity, autonomous driving software.
Nvidia	Santa Clara, CA, USA	1993	AI computing for autonomous vehicles	AI computing: Hardware and software for autonomous vehicles, including GPUs and deep learning technologies.
Baidu	Beijing, China	2000	Apollo self-driving platform	Apollo self-driving platform: Open-source software, sensors, and cloud services for autonomous driving.
Mobileye	Jerusalem, Israel	1999	Self-driving solutions and EyeQ chip	Self-driving solutions and EyeQ chip: Advanced driver-assistance systems (ADAS), EyeQ family of SoCs for processing.

LEADERSHIP INTERVIEW

Danny Shapiro

Vice President of Automotive

Industry Leadership Interview: Insights from NVIDIA about Artificial Intelligence in AVs

We also had the opportunity to sit down with Danny Shapiro, the Vice President of Automotive at NVIDIA, a driving force behind the technological revolution in autonomous vehicles. As the industry undergoes a transformation unlike any other, we delve into the insights and expertise of a visionary leader shaping the future of mobility. Here we explored the challenges, breakthroughs, and vision that are propelling autonomous vehicles into the next era.

In your position as a VP at NVIDIA, what do you think about the current state of the autonomous vehicle industry?

Danny Shapiro: This is an exceptionally dynamic era within the transportation sector, marked by the pervasive influence of artificial intelligence (AI) and the emergence of the industrial metaverse. What we have termed the „Ominiverse” represents our comprehensive solution in this transformative landscape. From the earliest conceptualization and stylistic considerations to the various stages of design, engineering, manufacturing, autonomous vehicle (AV) development, and even marketing and sales within the retail domain, every facet of the automotive industry is undergoing profound metamorphosis.

The forthcoming wave of generative AI promises to assume a pivotal role in each of these specialized domains. Moreover, the advent of digital twins is proving instrumental in enhancing operations across the board, facilitating their seamless integration. In this context, the Ominiverse provides a collaborative platform for designers and professionals worldwide, transcending geographical constraints. Virtual environments enable disparate experts to collectively contribute to the vehicle’s composition. Design reviews unfold in a virtual realm, allowing real-time interaction and immediate visualization of alterations.

Yet, the integration extends beyond design to encompass engineers in distinct silos and the production facility, fostering a comprehensive approach. Facilitating this integration is the Universal Scene Descriptor (USD), a novel standard that harmonizes the

collaboration of various departments. A design modification automatically reflects in the engineering sphere and synchronizes with the production floor.

Consequently, factory planners can meticulously construct a physics simulation of the manufacturing facility before its physical realization. An array of cutting-edge technologies, coupled with AI, plays an instrumental role across this spectrum. Generative AI optimizes factory layouts, while AI, which has been under development for an extended period, is now experiencing an inflection point, rendering its accessibility to a broader audience. For example, ChatGPT exemplifies how virtually anyone can assume the role of a programmer, possessing an AI copilot to enhance their professional endeavors.

The impact of AI and related technologies is felt throughout the entire product life-cycle. Customers can engage in virtual test drives, configure and personalize vehicles through immersive VR experiences, and make informed decisions prior to purchase. Furthermore, the realm of maintenance and repair is witnessing substantial enhancements, particularly through predictive maintenance practices and the utilization of augmented reality for training purposes.

Autonomous vehicle development, while a prominent aspect, represents only one facet of our extensive involvement within the automotive industry. The confluence of AI, virtualization, and cutting-edge technologies is reshaping the landscape and driving innovation across all fronts.

Can you provide a little bit of internal details of how you guys have been approaching the development of AV technology in the last few years?

Danny Shapiro: We are a comprehensive, full-stack company, engaged in diverse aspects of automotive technology. Our endeavors encompass the development of proprietary processors, the creation of an entire in-car platform, the design and implementation of full-stack software, and the orchestration of an operating system. Within this framework, we proudly offer Drive OS, a solution trusted by numerous automakers, truck manufacturers, and robo-taxi enterprises. Additionally, our portfolio features DriveWork software, a middleware solution housing a myriad of algorithms and deep neural networks, meticulously tailored for vehicular applications.

The software components encompass a multitude of deep neural networks (DNNs) optimized for distinct purposes within the vehicle. These DNNs are designed to perform intricate functions such as pedestrian detection, lane detection, and sign recognition. Furthermore, they are meticulously customized to align with the specific sensory input from LiDAR, RADAR, and camera systems. Notably, our approach extends to a comprehensive „free space” DNN, dedicated to discerning the absence of objects, thereby identifying the open road for safe navigation. The amalgamation of these neural networks and algorithms offers redundancy and diversity, ensuring paramount safety, which stands as our foremost priority.

Our distinctive approach involves the collaborative development of automotive systems with partners. We do not undertake the vehicle manufacturing process, but we are committed to creating the essential „brain” and the software stack. This comprehensive approach spans the entire spectrum, from the uppermost software layers to the fundamental hardware. Our clientele varies in terms of in-house technology capabilities and staffing, permitting them the flexibility to either adopt our complete stack, sensor suite, and computer system or selectively integrate specific components, aligning with their internal resources.

Consequently, a multitude of customers opt to incorporate our hardware „brain” while selectively implementing portions of our software stack, allowing them to craft their proprietary applications. Our partnerships are diverse and encompass a wide array of automotive manufacturers, including carmakers, truck manufacturers, robo-taxi operators, and shuttle service providers. Each engagement is distinctive, recognizing the inherent complexity of automotive technology. No single entity possesses the capability to address all aspects comprehensively.

Our collaborations, such as the one with Mercedes-Benz, exemplify close cooperation between our engineers and those of our partners. We provide substantial software resources, and the eventual product customization rests with our collaborators, who tailor the solution to meet their unique brand identity, specific use cases, and desired features. Our collaborative network spans globally, extending to esteemed brands like Jaguar, Land Rover, Volvo, Polestar, and numerous enterprises in China. These entities leverage our foundational platform while retaining the ability to fine-tune it to suit their individual requirements.

A pivotal development in the automotive industry is the paradigm shift toward the concept of a software-defined vehicle. Central to this model is a high-performance onboard computer that is amenable to over-the-air updates, facilitating the seamless addition of new features and capabilities throughout the vehicle’s operational lifespan.

How is NVIDIA advancing in AI?

Danny Shapiro: We possess a distinctive advantage predicated on several key attributes. While we are deeply immersed in the automotive sector, it is pivotal to note that our core identity remains that of an accelerated computing company. This strategic positioning empowers us to direct substantial resources toward ongoing research and development endeavors in the realm of artificial intelligence, transcending the confines of the automotive domain. The resultant innovations find application across an expansive spectrum of industries, underpinning our unique position in the market.

One illustrative case is our substantial involvement in the healthcare industry, particularly in the domain of cancer detection. Within this context, AI technology plays a pivotal role by aiding radiologists in the analysis of various medical scans, facilitating

diagnostic processes, and contributing to disease mitigation. Remarkably, the very technology designed for cancer cell detection can be readily repurposed for pedestrian detection. Though the datasets and training processes differ, the underlying algorithms exhibit striking similarities. Our capacity to leverage insights and methodologies from diverse industries and seamlessly integrate them into the automotive sector represents a distinctive and invaluable capability.

Notably, our commitment extends beyond in-car technologies. An equally significant facet of our strategy encompasses the development of cutting-edge computer systems and AI infrastructure within the data center and cloud environment. What sets us apart is the uniformity of architecture employed across both realms, synchronizing the design and functionality of data center components with their in-car counterparts. This alignment empowers developers with a profound advantage in the AI development process, encompassing the training phase and the real-time inference stage. The seamless integration of these critical components represents a pivotal stride in AI development.

Furthermore, it is imperative to acknowledge the perpetual nature of AI development in the automotive sector. This iterative process entails continuous cycles of training, testing, deployment, data collection, and further refinement. The software within vehicles remains in a state of constant evolution, mirroring the update model familiar to smartphone users. The expectation for modern vehicles is rapidly aligning with this paradigm, with consumers increasingly anticipating ongoing software enhancements and updates. The ability to provide such continuous improvement is swiftly becoming a decisive factor in the market. In essence, the vehicle ownership experience is transitioning toward a model akin to that of contemporary smartphones, wherein software updates and enhancements are integral to user satisfaction and functionality.

Is NVIDIA developing AV safety mechanisms?

Danny Shapiro: Certainly. The intricacies of system development are contingent upon the specific level of autonomy the system aims to achieve. A critical consideration is whether the system is designed for full autonomy or driver assistance, as these determinations govern the requisite fail-operational mechanisms. In driver assistance systems, the presence of a human operator behind the wheel serves as a backup. Conversely, in the context of autonomous vehicles, such as robo-taxis, the absence of a steering wheel and pedals necessitates the implementation of robust fail-operational systems.

These fail-operational systems encompass a core computer, complemented by a backup computer. Although the backup may not replicate the full functionality of the primary unit, it possesses the capability to safely guide the vehicle to the side of the road, initiate a controlled stop, and request assistance in the event of a primary system failure. The implementation of such systems necessitates a fusion of diverse techniques at

the chip level, including the incorporation of redundancy and diversity in sensor types, overlapping sensor deployments, and a repertoire of algorithms, including various deep neural networks.

Redundancy extends to the software domain as well. For instance, multiple algorithms may concurrently execute, each performing similar calculations to cross-verify results. This multi-pronged approach is fundamental to the paramount consideration of safety, encompassing all aspects from chip architecture, software components, to sensor boards.

One prevailing challenge that has significantly complicated the timeline for the widespread adoption of self-driving vehicles pertains to the complexity of the problem. Initial estimates and expectations, as far back as 2015, failed to account for the intricacies and unforeseen challenges encountered in this domain. The foremost concern in the pursuit of autonomous vehicles is the assurance of safety, prompting rigorous safety measures and validation procedures.

A pivotal facet of our approach revolves around simulation. Our product, Drive Sim, is instrumental in creating a digital twin of urban environments within the Ominiverse framework. This digital replica encompasses road infrastructure, signage, traffic flow, other vehicles, pedestrians, cyclists, and an array of scenarios. These scenarios may encompass rare, challenging, or potentially dangerous situations that are impractical or unsafe to replicate in the real world. Simulation empowers us to execute millions of miles of virtual testing, including scenarios involving variable weather conditions and lighting effects, such as blinding glare during sunset. This augmented approach supplements real-world testing, significantly enhancing the rigor of our validation processes.

Our simulation techniques encompass both software in the loop and hardware in the loop. Notably, our Constellation product serves as a simulator equipped with an array of GPUs to generate synthetic data, simulating the sensory inputs of cameras, RADAR systems, and LiDAR sensors. This synthetic data is subsequently fed into the actual drive computer situated within the data center. The drive computer processes this data, unaware of its simulation status, effectively believing it is navigating real-world environments. Subsequently, the drive computer renders driving decisions, including acceleration, braking, and steering responses, which are then fed back into the simulator. This hardware-in-the-loop methodology enables comprehensive testing to evaluate the system's responses to a multitude of scenarios, such as the detection of pedestrians, night-time child safety scenarios, and signage recognition. The outcome of these tests serves to identify potential issues requiring software refinement or validation of system functionality.

How is Nvidia managing the substantial volume of data involved in autonomous vehicle (AV) systems?

Danny Shapiro: Indeed, our endeavor entails an unprecedented undertaking, characterized by the creation of vehicles and fleets on a scale heretofore uncharted. While engineering a few vehicles represents a manageable feat, the transition to managing tens of thousands, hundreds of thousands, or even millions of vehicles on the road poses a distinctly formidable challenge. Consequently, we have meticulously constructed our operational framework from the ground up, encompassing comprehensive vehicle design and manufacturing, as well as the development of a robust data center infrastructure. This comprehensive approach is underpinned by our commitment to gaining an intricate understanding of the scale and intricacies of the challenge at hand. Without this firsthand knowledge, we cannot proficiently deliver solutions to our clientele.

It is important to clarify that we are not in competition with tier one suppliers or original equipment manufacturers. Our pursuit of these endeavors on a smaller scale serves as a pivotal mechanism for acquiring invaluable insights into the methodologies, workflows, and infrastructural components required for the realization of our vision. This insight enables us to offer robust and well-informed solutions to our partners and customers.

Our efforts extend to the development of systematic workflows for data collection, archival, curation, and labeling. These steps are integral to the preparation of datasets for training and validation purposes, and artificial intelligence plays a central role in enhancing the efficiency of these workflows. Moreover, we leverage AI in the very development of AI models. As we traverse vast distances, we employ AI algorithms to classify and categorize the data acquired, given that the majority of miles traveled typically involve familiar and well-understood scenarios. Our objective is to discern and document those rare and exceptional circumstances, thus ensuring their retention in our curated dataset.

Furthermore, we harness the capabilities of synthetic data generation to augment our dataset with infrequent or unusual scenes. A technique known as „neural reconstruction” permits us to transform recorded drives into three-dimensional representations of the environments traversed. These 3D scenes serve as the foundation for creating diverse permutations and scenarios. This approach allows for the identification and manipulation of vehicles within the scene, enabling the generation of an array of novel scenarios, all derived from a single drive. Consequently, we can construct numerous distinct scenes, enriching our dataset with valuable synthetic data for AI training and validation purposes.

How are you developing cybersecurity technologies or partnering with companies advancing in this area?

Danny Shapiro: As previously mentioned, our corporate identity extends beyond the conventional automotive realm, as we originate from the data center industry. Our core mission involves the seamless integration of data center technology and high-perfor-

mance computing into the automotive domain. Consequently, the extensive knowledge and expertise acquired in managing data centers serving critical functions, such as those in banking and healthcare, are harnessed in our automotive systems.

Within this framework, we have implemented a comprehensive suite of cybersecurity measures that have proven pivotal in safeguarding our automotive solutions. These measures encompass encryption, authentication protocols, and virtualization techniques, each of which plays a vital role in fortifying various system components. The assimilation of these data center technologies into our automotive systems affords us the ability to leverage a wealth of expertise and insights, recognizing the paramount significance of cybersecurity in our endeavors.

Furthermore, our focus extends to the implementation of stringent cybersecurity measures at the device level, encompassing devices interconnected via Bluetooth, Wi-Fi, or cellular modems. These security measures aim to establish effective firewalls, preventing unauthorized access or tampering. At the chip level, we have integrated cutting-edge technology, such as secure boot mechanisms and encrypted over-the-air update protocols, to safeguard against unauthorized modifications.

Moreover, our commitment to cybersecurity extends to the application of artificial intelligence. We are actively engaged in pioneering developments at the data center networking level, wherein AI algorithms are instrumental in the continuous monitoring of chip behavior. AI-equipped systems possess the capacity to detect anomalies by discerning deviations from established norms. For instance, in scenarios where the tire pressure monitoring system initiates a software update, AI algorithms swiftly recognize this as abnormal behavior, enabling rapid intervention and mitigation.

In conclusion, cybersecurity remains a central and paramount aspect of our work. While the full extent of our cybersecurity strategies cannot be disclosed in detail, rest assured that it represents a top-tier priority within our operational framework.

How have you been developing hardware?

Danny Shapiro: Certainly, when reviewing our technological roadmap across various temporal horizons, it becomes evident that our unwavering commitment resides in consistently pushing the boundaries of performance. This pursuit of performance excellence transcends domains, encompassing graphics, computing, and the rapidly advancing field of artificial intelligence. Our enduring objective remains the attainment of industry-leading performance metrics. Concurrently, we maintain a vigilant focus on augmenting energy efficiency, achieved through meticulously crafted strategies that encompass the reduction of die size and the implementation of power management techniques to deactivate dormant chip components.

Our dedication to optimizing energy consumption emanates from our extensive background in designing systems for laptops, smartphones, tablets, and mobile devices. In

these contexts, the preservation of battery life stands as a pivotal consideration. Notably, each successive generation of our technology showcases noteworthy advancements in the realm of performance per watt, surpassing the capabilities of its predecessor. Furthermore, our commitment to energy efficiency extends to the software domain, where sophisticated algorithms facilitate the systematic hibernation of underutilized system components, thus contributing to energy conservation.

Central to our roadmap is the primacy of performance, a fundamental principle that has consistently proven to be a linchpin of our success. In the context of autonomous vehicles, this enhanced performance directly translates into an augmentation of safety. Notably, the expanded processing capacity enabled by heightened performance empowers AVs to process data from an augmented array of sensors, including those characterized by higher resolutions. Furthermore, this expanded performance capability permits the execution of more intricate deep neural networks, instrumental in the detection and prediction of behaviors. This includes the ability to distinguish between distracted and attentive pedestrians, a nuanced aspect of AV safety. Ultimately, the correlation between heightened performance and increased safety is indisputable, underscoring the pivotal role of superior performance in the evolution of AV technology.

What are the main challenges in engineering electric vehicles?

Danny Shapiro: Across cities worldwide, there is a notable proliferation of deployment and testing endeavors involving autonomous vehicles. The Bay Area, in particular, stands as a vivid testament to this global trend, where a diverse array of autonomous vehicle prototypes and iterations undergo daily trials. Indeed, certain robo-taxi enterprises in San Francisco have procured licenses permitting operational deployment without a human driver within the vehicle, thus offering their services to paying customers.

While these advancements hold great promise, it is imperative to acknowledge that autonomous vehicles have not yet attained mainstream adoption. Our foremost commitment and emphasis remain dedicated to securing the requisite safety approvals that are indispensable for this transformative technology. Our objective is nothing short of ensuring that these autonomous vehicles exhibit the capacity to adeptly navigate and respond to an exhaustive spectrum of potential scenarios. This ambition is rooted in the understanding that autonomous vehicles, once deployed at scale, will demonstrably surpass human-driven counterparts in terms of safety. Nevertheless, the imperative is to meticulously account for every conceivable circumstance and eventuality.

Our ongoing endeavors revolve around the refinement of the technology underpinning autonomous vehicles, an expansive expansion of testing protocols, and an unwavering commitment to broadening the scope of situations that these vehicles can competently address. This mission extends to the formidable challenge of accommodating the often unpredictable behavior of human drivers, with the overarching aim of enhancing safety

for all stakeholders sharing the roadways. Our dedication to this pursuit encapsulates a comprehensive commitment to the safety and well-being of all individuals both within and beyond these autonomous vehicles.

What are some key considerations in the AV industry?

Danny Shapiro: Within the realm of the autonomous vehicle (AV) industry, there exists a plethora of indispensable considerations that merit meticulous examination. It becomes evident that the sphere extends far beyond the confines of isolated chip performance or energy efficiency, as these are but constituents of a much broader equation. The fulcrum of this multifaceted domain is the comprehensive software stack that resides within the autonomous vehicle, underpinning its core functionalities. Yet, it is often the intricate interplay of data collection, artificial intelligence (AI) training, and rigorous simulation testing, accompanied by the ongoing evolution of applications and software, which frequently eludes the purview of the casual observer.

This intricate development workflow, while potentially concealed from the awareness of the average consumer, holds pivotal significance for those entrenched within the industry's inner circles. Beyond the software-centric aspects, the transformative scope of the automotive sector extends to myriad dimensions, notably encompassing automotive design. Envision a future where vehicular collisions become obsolete, precipitating a seismic shift in design paradigms that render traditional steel and airbag usage redundant. Every facet of the design, engineering, and manufacturing process stands poised for profound transformation, where artificial intelligence, particularly generative AI, emerges as a vanguard of this renaissance.

Generative AI, exemplified by technologies like ChatGPT, ushers in a new era of artificial intelligence capable of generating an eclectic array of outputs from diverse inputs. It possesses the capacity to transmute textual input into visually captivating imagery, transmute text into video content, and even craft original visual and video compositions drawn from pre-existing materials. While the technology remains in its incipient stages, its potential to revolutionize multifarious domains, ranging from design and engineering to manufacturing and tailored retail experiences, is undeniably palpable.

Consider the possibility of individualized television advertisements, meticulously tailored to each viewer's preferences, featuring a vehicle traversing their own neighborhood streets and parking in their driveway. AI, in synergy with the Ominiverse, holds the transformative power to reshape every facet of the automotive industry. Consequently, the depth and multidimensionality of this subject matter is readily apparent. Should you embark on an exploratory journey in this transformative arena, we remain at your disposal to furnish supplementary content, video references, or to actively participate in follow-up dialogues that delve deeper into this paradigm-shifting subject. Furthermore, we extend an open invitation for fact verification or quotation authentication as deemed necessary.

Edge Computing

Data volumes generated by AVs can reach staggering proportions, in some cases more than 1 GB per second. Toyota predicts that the volume of data exchanged between cars and the cloud could reach 10 exabytes per month by 2025, which is 10,000 times the current amount. However, the cloud infrastructure was not originally designed to process such massive quantities of data rapidly enough to support autonomous vehicles.⁴⁶

Transferring a fraction of this data to a cloud-based server for analysis is impractical due to bandwidth constraints and latency issues. For example, a 1ms latency corresponds to a very short distance, and this precision is necessary to avoid collisions and ensure smooth driving. It has been also estimated that the transmission of data over a network would require a minimum of 150-200ms, which is a significant amount of time considering the car is in motion and real-time decisions regarding car control need to be made.

Edge computing solutions offer real-time data processing capabilities,

thereby minimizing reliance on network connectivity for decision-making. This not only reduces the need for online connectivity but also enhances the accuracy of decision-making.

Edge computing involves handling, storing, and interpreting data close to where it is created. To achieve this, AVs often require integration of two distinct in-vehicle computing systems. The first computer undertakes the substantial task of processing copious amounts of sensory data and images collected through cameras and various sensors. Concurrently, the second computer analyzes the processed image data, swiftly making intelligent decisions for the vehicle's safe navigation.^{42,43} The proximity of data allows for immediate data processing, empowering devices or vehicles to respond to information without delay.

Increasing security with Edge computing

Security is a paramount concern in the AV ecosystem, and edge computing supports this aspect effectively. Edge computing enhances the reliability of AVs by reducing dependence on distant cloud networks. Even in the event of network issues, AVs can

function effectively as critical processing occurs locally. Additionally, edge computing helps improve data security by reducing communication overhead and limiting exposure to potential data breaches during transmission to remote servers.

In the last three years, automakers have implemented various layers of protection and redundancy to safeguard against power, network, and compute failures. Autonomous vehicles are equipped with the capability to dynamically re-route and power network traffic, as well as decision-making processes, to ensure a safe stop. The integration of Internet of Vehicles (IoV) and edge computing into a comprehensive distributed edge architecture ensures reliability and availability, with data being rerouted through multiple pathways to maintain access to necessary information.

“A lot of the research community looks at fancy algorithms, but making it work in real time on the edge is something which is still very challenging, especially if you go for larger and neural networks.”

Alexander Wischnewski,
Managing Director and Co-Founder of driveblocks

Hardware Advancements for Edge Computing in AVs

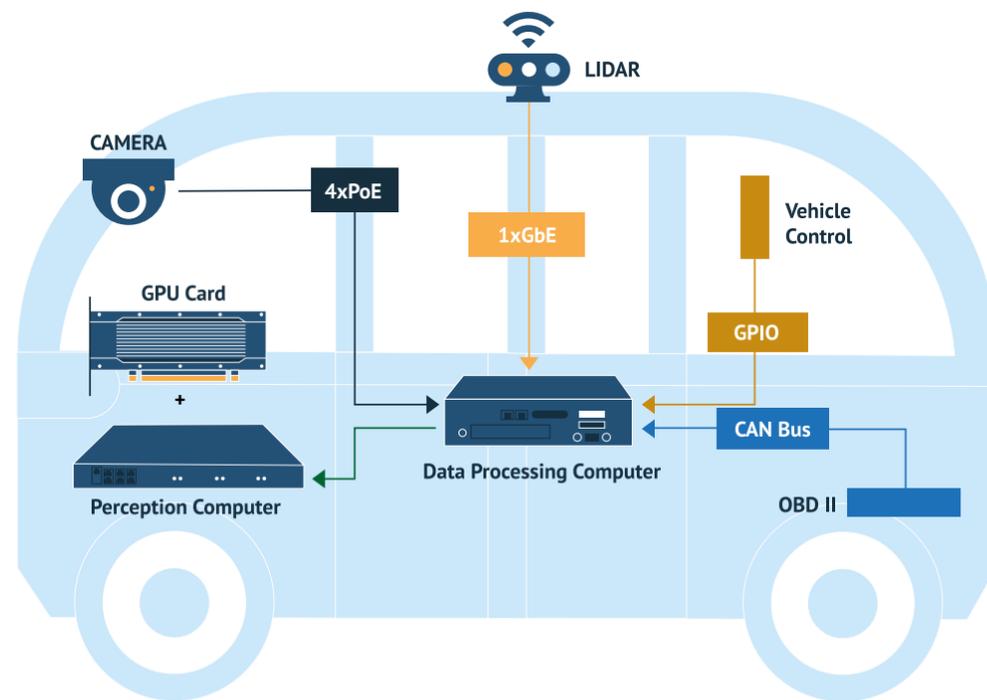
AVs rely on specialized hardware for edge computing tasks. While general-purpose CPUs and GPUs are commonly used, there's a growing need for dedicated AI accelerator chips. These chips are optimized for deep learning inference and are designed to strike a balance between power consumption, speed, accuracy, and cost. For example, in August 2023, Google announced the launch of the fifth generation of its tensor processing units (TPUs) for AI training and inferencing. In contrast to its predecessor, this iteration is provide a 2x enhancement in training performance efficiency for every dollar spent and a 2.5x improvement in

inferencing performance efficiency per dollar.^{44 45}

Among the others, Field-Programmable Gate Array and Application-Specific Integrated Circuit chips are gaining importance due to their ability to provide efficient and customized processing for specific AI models. For example, advanced processors, such as NVIDIA's Xavier and DRIVE platforms, have been widely adopted in AVs. These processors offer high computational power, energy efficiency, and support for AI and machine learning tasks.

In terms of power efficiency, a high power consumption of GPUs can impact the driving range and fuel effi-

ciency. Thus, AI accelerators that offer high performance with minimal power consumption are in demand. For instance, GTI's LightSpeur 2803S provides high power efficiency, achieving a rate of 24 TOPS/Watt by conducting all CNN processing within its internal memory, rather than relying on external DRAM. It can effectively classify 448x448 RGB image inputs at a rate exceeding 16.8 TOPS while consuming less than 700mW at its peak power usage, all while maintaining accuracy levels comparable to the VGG benchmark. Gyrfalcon's CNN-DSA accelerators possess reconfigurability, enabling support for CNN model coefficients of varying layer sizes and types.⁴⁶



AI-Powered Edge Computing Platforms Enable Autonomous Driving

Image credit: Lanner

Companies Developing Edge Computing for AVs

Big players have been pioneering the transformation of how autonomous vehicles function and interact with their environment using edge computing.

NVIDIA

The NVIDIA DRIVE integrates high-performance GPUs with AI software tools, enabling AVs to process vast amounts of sensor data in real-time. By deploying powerful AI hardware on board, NVIDIA enables AVs to make split-second decisions independently, without relying on external cloud servers.⁴⁹

NVIDIA's edge computing solutions are advantageous for autonomous vehicles, offering powerful processing with NVIDIA GPUs. These GPUs enable AVs to efficiently handle complex sensor data from cameras, LiDAR, and RADAR, reducing latency by processing data locally. This low latency enhances safety, as the DRIVE platform allows rapid analysis and response to potential road hazards, improving overall road safety for autonomous vehicles.

In 2021, Volvo Cars partnered with NVIDIA to utilize their DRIVE Orin™ technology for autonomous driving computers in their next-generation vehicles, building on their ongoing collaboration. This technology, in conjunction with in-house software development and advanced sensors, including LiDAR, steering, and braking systems, aims to enhance safety, personalization, sustainability, and continuous improvement through over-the-air software updates for Volvo's intelligent vehicle fleet.

In addition, in 2021, Zoox introduced a

specialized robotaxi designed for daily urban transportation needs, driven by NVIDIA DRIVE technology. This robotaxi is among the pioneers to offer bi-directional capabilities, marking a significant step forward in advancing intelligent urban mobility.⁵⁰

Qualcomm Technologies

Qualcomm Technologies is positioned in the field of wireless communication technology, as a significant contributor to edge computing solutions in the AV domain. Launched in 2020, the Qualcomm Snapdragon Ride Platform showcases the integration of AI processing with vehicular systems, enabling AVs to process data from various sensors, including cameras and LiDAR, at the edge. This platform equips AVs with the computational power required to analyze complex environments and make informed decisions instantaneously.^{42 51}

The Snapdragon Ride Platform, at its core, enables effective sensor fusion, seamlessly integrating data from various sensors. This fusion enhances the accuracy of AVs' perception systems and deepens their understanding of the surrounding environment, improving overall safety and performance. Notably, Qualcomm's solutions emphasize reliability, ensuring that AVs equipped with their edge computing technology can remain operational even in scenarios with limited or intermittent connectivity.

In 2022, Volkswagen's Cariad software division announced a partnership with Qualcomm to source system-on-chips (SoCs) from Qualcomm's Snapdragon Ride portfolio for their autonomous driving software. These SoCs are a crucial hardware component for Cariad's standardized and scalable computing

platform, enabling autonomous driving up to Level 4 standards, a central part of Volkswagen Group's future strategy.⁵²

Lanner

Lanner is currently engaged in multiple autonomous driving projects. Since 2022, Lanner has offered AI-powered edge computing platforms designed to enable both autonomous and intelligent driving.

Lanner's edge computing solutions cater to the initial pre-processing stage of data collected by autonomous vehicles. Equipped with video cameras and an array of sensors such as ultrasonic, LiDAR, and RADAR systems, AVs rely on quick and efficient data aggregation and compression. Lanner's in-vehicle computers are equipped with multiple I/O ports that facilitate the seamless reception and transmission of data, thus expediting data processing.

Real-time Operating Systems for Autonomous Vehicles

A Real-Time Operating System (RTOS) represents a specialized operating system (OS) adept at orchestrating hardware resources and operations. It manages a spectrum of activities simultaneously and within established time boundaries. These tasks range from coordinating application program scheduling and writing data onto storage disks to transmitting information across networks.

In AVs, RTOS systems are used for sensor fusion, control systems, safety-critical functions, and real-time communication within the vehicle and with external infrastructure. Moreover, they enable redundancy and fail-safe mechanisms, real-time mapping and localization, and secure over-the-air updates to keep the vehicle's software current and secure. RTOS also provides hardware abstraction, making it easier for developers to create software that can run on various hardware platforms. In this way, companies utilize RTOS to deliver the precision, low latency, and reliability required for the complex task of autonomous driving, ensuring the safe and effective functioning of these vehicles on the road.⁵³

Advancements in RTOS Systems for AVs

Specific types that have garnered significance in the context of AVs. The

technologies presented below have emerged as crucial factors in AV development due to their inherent reliability, ability to enhance performance, and robust developer support.

Autoware Foundation

Autoware, an open-source project, aims to provide a comprehensive software stack for self-driving technology. It utilizes ROS and various RTOS components to facilitate AV development.

Automotive Open System Architecture (AUTOSAR)

AUTOSAR serves as an software development standard for Automotive RTOS and electronic control units (ECUs). Industry players such as KPIT Technologies, RTA-OSEK (from ETAS, a part of Bosch), and Elektrobit utilize AUTOSAR to facilitate the harmonization of automotive software, enhancing interoperability across various components. It supports the integration of different RTOSes and middleware components, promoting interoperability among various AVs.

Noteworthy AUTOSAR trends in 2023 encompass a heightened emphasis on cybersecurity, empowering secure vehicle-to-everything (V2X) communication, bolstering support for over-the-air (OTA) updates, and seamless integration of artificial intelligence to advance driver assistance systems (ADAS) and autonomous driving capabilities.⁵⁴

Automotive Grade Linux (AGL)

As a specialized version of the Linux Open-Source operating system, AGL is tailored specifically for automotive applications, offering high-standard RTOS capabilities. With the participation of ten automotive brands and 140 subsystem suppliers, the AGL project

strives to provide a versatile platform for building innovative and connected automotive systems.

Connected Vehicle System Systems Alliance (COVESA, formerly GENIVI)

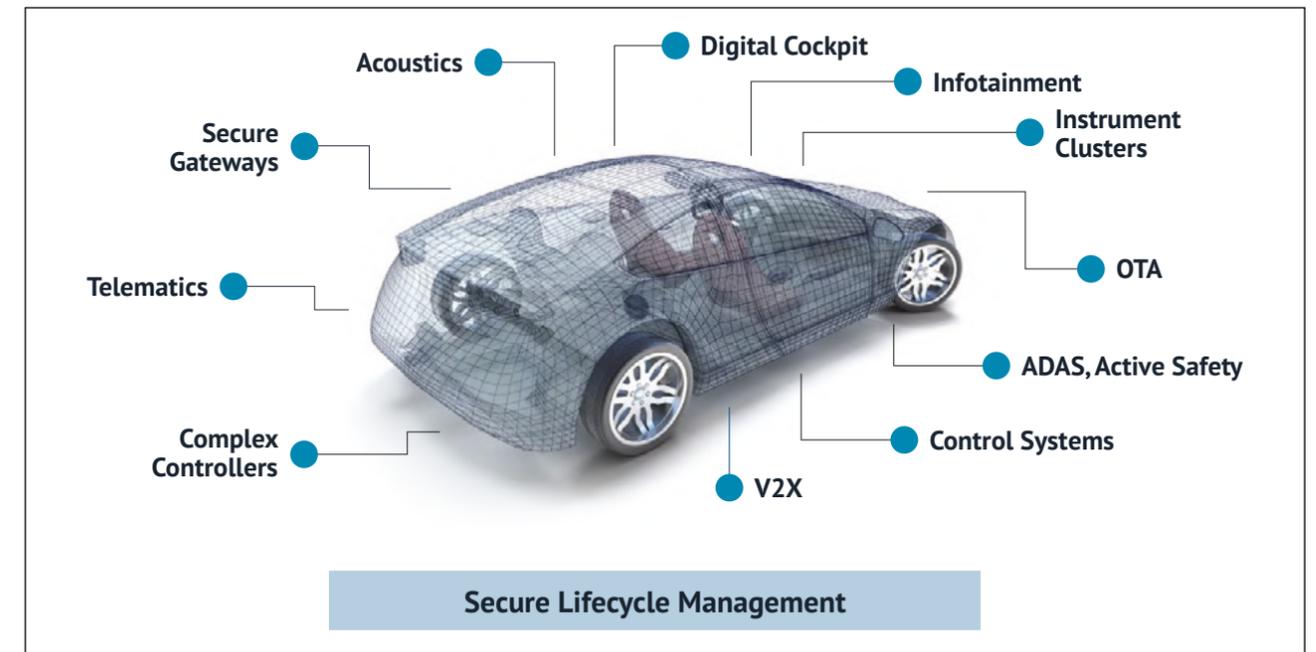
COVESA focuses on developing reference approaches for automotive systems, including RTOS solutions. Its efforts include ensuring compatibility and coexistence with AUTOSAR-based systems, promoting seamless integration across the automotive software landscape.

BlackBerry QNX Automotive

BlackBerry QNX Automotive stands out for its explicit design to cater to embedded automotive systems. Prioritizing speed, reliability, and security, it has found deployment in over 235 million vehicles globally. Its versatility spans various automotive ECUs, ranging from telematics and infotainment to advanced driver assistance systems (ADAS) and safety features. It offers a microkernel architecture, making it suitable for safety-critical applications. It is used in various AV platforms for functions like sensor fusion, control, and communication.

BlackBerry QNX takes valuable insights from its AVIC system and uses them to help automotive manufacturers, suppliers, SMEs, schools, and research groups achieve ISO 26262 safety certification for their production systems. Strategy Analytics, an independent research firm, has reported that more than 215 million vehicles worldwide utilize BlackBerry's QNX software in 2022.

This marks a 20 million increase from the previous year. Automakers utilize BlackBerry QNX software for a variety of applications in today's interconnect-



BlackBerry QNX Automotive Software. Image credit: Blackberry

ed vehicles, such as digital dashboards, advanced driver-assistance systems, instrument panels, sound systems, and entertainment systems. Companies like BMW, Bosch, Continental, Honda, Mercedes-Benz, Toyota, and Visteon have incorporated this embedded software in their vehicles.

VxWorks

xWorks is a renowned and extensively adopted commercial Real-Time Operating System (RTOS) that delivers consistent and rapid response times. This high-performance RTOS boasts over three decades of industry experience and more than 2 billion installations across a diverse range of embedded systems worldwide. One of the notable aspects of VxWorks is its classification as a „Hard RTOS.”

This distinction places it among the elite RTOS solutions favored in AVs.

Hard real-time capabilities ensure that it meets stringent timing requirements, making it suitable for AVs where precise and deterministic responses are imperative. The manufacturer also has a proven history of providing fault-tolerant operation, essential in environments where AV failures can have severe consequences. Finally, the adaptability of the technical solutions ensures that VxWorks can be integrated into a wide array of vehicle applications, from simple embedded control systems to complex tasks like autonomous decision-making.

Green Hills Software

This company specializes in safety-critical software solutions, including RTOSes. Its INTEGRITY RTOS is used in AVs to enable real-time processing and secure partitioning of tasks. Since the beginning of 2023, Infineon has been working together with Green

Hills Software to provide extensive and reliable safety and security solutions tailored for the TRAVEO T2G MCU families in the automotive sector.

This software solution has been fully tested, creating a comprehensive package suited for various automotive uses, including electrification, managing vehicle body controls, gateway functions, and infotainment. This partnership provides car manufacturers with a ready-to-use, integrated solution. It is designed to be efficient in its use of memory, yet it does not compromise on quality, performance, or reliability.

Apex.AI

Apex.AI is dedicated to improving its RTOS known as Apex.OS, which was launched in 2020. Engineered for exceptional scalability and adaptability, Apex.OS is meticulously crafted to

serve a diverse spectrum of applications in the domain of AVs.⁵⁵ This system includes an easy-to-use software development kit (SDK) to improve advanced automotive software creation.

This product functions as a meta-operating system, enabling the rapid and safe development of complex applications, significantly faster than traditional methods. It offers a comprehensive collection of ready-to-use SDKs and tools to assist in application development, debugging, and testing.

When implemented, the operating system facilitates a smooth transition from software prototyping to production in the automotive industry, saving time and resources for users. Apex OS aims to enable the transition from hardware-centric to software-centric vehicles, providing a comprehensive operating system to develop mobility applications in an optimal manner. Apex.AI aspires to be the Android of the automotive world, striving to become the dominant operating system in the industry.

Cognata

Cognata is a specialized company in developing simulation and testing solutions tailored for AVs. The RTOS developed by Cognata is purpose-built for integration within simulation and testing settings, and it further holds applicability in the operational landscape of production AVs.⁵⁶ Cognata has introduced a new service utilizing Microsoft Azure, enabling automotive companies to virtually test ADAS/AV sensors in realistic simulation settings.

This platform offers a wide range of ADAS/AV sensors and robust simulation tools, facilitating quick and comprehensive analysis of sensor

placement and capabilities on vehicles. Users can conduct tests in various environments, including urban, highway, and off-road settings, at different times of the day and under diverse weather conditions. This new product runs on Microsoft Azure and uses AMD processors and GPUs.

It aims to help automotive customers efficiently assess ADAS/AV sensors through authentic simulation environments. Cognata's automated driving perception Hub addresses this by offering a photorealistic environment for testing various sensor models and custom presets across terrains, times of the day, and weather conditions. This significantly reduces the time needed for sensor evaluation.

Cognata's collaboration with Microsoft accelerates the digital transformation of automakers using Azure's global cloud, services, and computing capabilities, thereby fast-tracking the development, verification, and validation of ADAS/AV features.



PARTNER INTERVIEW

Samet Kütük

Autoware Foundation Board Member

Advancing Open-Source Development in the Automotive Industry

In this interview, Samet Kütük, a board member and Marketing/Go-To-Market working group chair of the Autoware Foundation and CTO and co-founder of Leo Drive, shares insights into his eight-year journey developing level four autonomous vehicles. He discusses the crucial role of the Autoware Project, the world's leading open-source initiative for autonomous driving.

Can you give us an introduction to what Autoware is?

Samet Kütük: The Autoware Project originated in 2015 at Nagoya University in Japan, initiated by Professor Shinpei Kato. Following its foundation the next year, Autoware has grown into being the world's leading open-source project for autonomous driving, boasting more than 70 members, including many prominent companies working on autonomous vehicle technology, as well as 23 university partners.

How does one become a member of Autoware?

Samet Kütük: Autoware is an open-source project hosted on GitHub. Individuals or companies interested in joining can explore the codebase on their own. If they wish to engage further, they can reach out to us. The board evaluates the potential value of new members, offering different membership packages, including premium memberships and industry memberships, with varying fee structures for annual participation.

Why is the Autoware project open source?

Samet Kütük: The Autoware project adopts an open-source approach to address issues related to proprietary solutions. Many players in the industry follow proprietary models, which lack transparency and can create barriers for vehicle manufacturers (OEMs) and any potential autonomy users. Autoware's open-source nature simplifies onboarding for OEMs, making the process more straightforward and cost-effective. This approach also allows for concept validation without heavy initial investments, providing a flexible and accessible platform.

Does Autoware accelerate the development of autonomous vehicles?

Samet Kütük: Absolutely. Autoware not only accelerates development but also aligns with the software-defined vehicle paradigm, emphasizing openness and transparency. Collaborative frameworks like Eclipse SDV and SOAFEE indicate a move towards more open approaches in the industry. Autoware's open ecosystem facilitates collaboration between applications and hardware, enabling a smoother development process.

Can you tell us more about the Robot Operating System (ROS)?

Samet Kütük: Autoware is built on the Robot Operating System (ROS), a middleware with a wide audience. ROS simplifies system understanding and offers a direct path to product development. The flexibility extends to operating systems, with partnerships with major companies like Arm, providing custom builds to support the architecture. ROS plays a crucial role in data exchange, connecting vehicle components, sensors, and the operating system.

What feedback have you received from people and members who've used the operating system?

Samet Kütük: Member companies, including Leo Drive, develop autonomous solutions using generic Linux distributions for operating systems. While generic Linux distributions are suitable for initial development, some companies choose more specialized OSs, for production-ready systems once prototyping for concept validation is complete. Autoware project also has a direct path to use safety-capable operating systems of which we are discussing with our alliance partners.

Where do you think we are with autonomous vehicles at the moment?

Samet Kütük: Assessing the current state of autonomous vehicles is challenging. Even well-funded companies, like Argo.AI and Cruise, face difficulties, leading to operational restrictions, or closing shop. Regulatory uncertainties, especially for autonomous vehicles operating in densely populated urban areas, present significant hurdles. However, there are already significant success stories in geo-fenced applications in controlled environments, such as ports and warehouses.

What's your vision for the future of autonomous vehicles? Do you think geo-fenced areas will be the first application?

Samet Kütük: Personally, I see good adoption in geo-fenced and controlled environments. While robo-taxis are not excluded from the future, regulatory compliance is a priority. Beyond regulation, technology development poses challenges, especially in diverse environmental conditions. Success stories are emerging in controlled environments, addressing transportation gaps and contributing to a greener planet.

How do you believe autonomous vehicles will benefit society?

Samet Kütük: Autonomous vehicles offer numerous societal benefits, including reduced road accidents caused by human factors. Shared mobility can fill transportation gaps, leading to fewer vehicles on the road, decreased traffic congestion, and lower greenhouse emissions. The positive impact extends to creating a more sustainable and environmentally friendly planet.

Regarding Autoware, is there anything we haven't discussed that you think is relevant for the report?

Samet Kütük: When considering Autoware, it's crucial to understand that it is a full-stack software for autonomous driving, covering everything from vehicle and sensors to perception, localization, planning, and control. Autoware replaces human senses in a vehicle with sensors, transforming a traditional vehicle into a self-driving platform. Additionally, our commitment to the software-defined vehicle paradigm, through collaborations with external alliances like SOAFEE, Eclipse SDV, AVCC, COVESA, and AUTOSAR is integral to our future endeavors.

Communication and Connectivity

This chapter delves into the intricate network of communication channels and connectivity protocols that enable AVs to interact with their environment, other vehicles, and infrastructural elements. We give a brief overview of the current status of Vehicle-to-Vehicle (V2V) and the investments made in Vehicle-to-Everything (V2X).

We also look at the role of 5G networks and beyond in enabling the responsiveness and decision-making capabilities of autonomous vehicles. Finally this chapter addresses the challenges and solutions related to

cybersecurity. We examine the latest advancements in Intrusion Detection and Prevention Systems (IDPS) and blockchain technology.

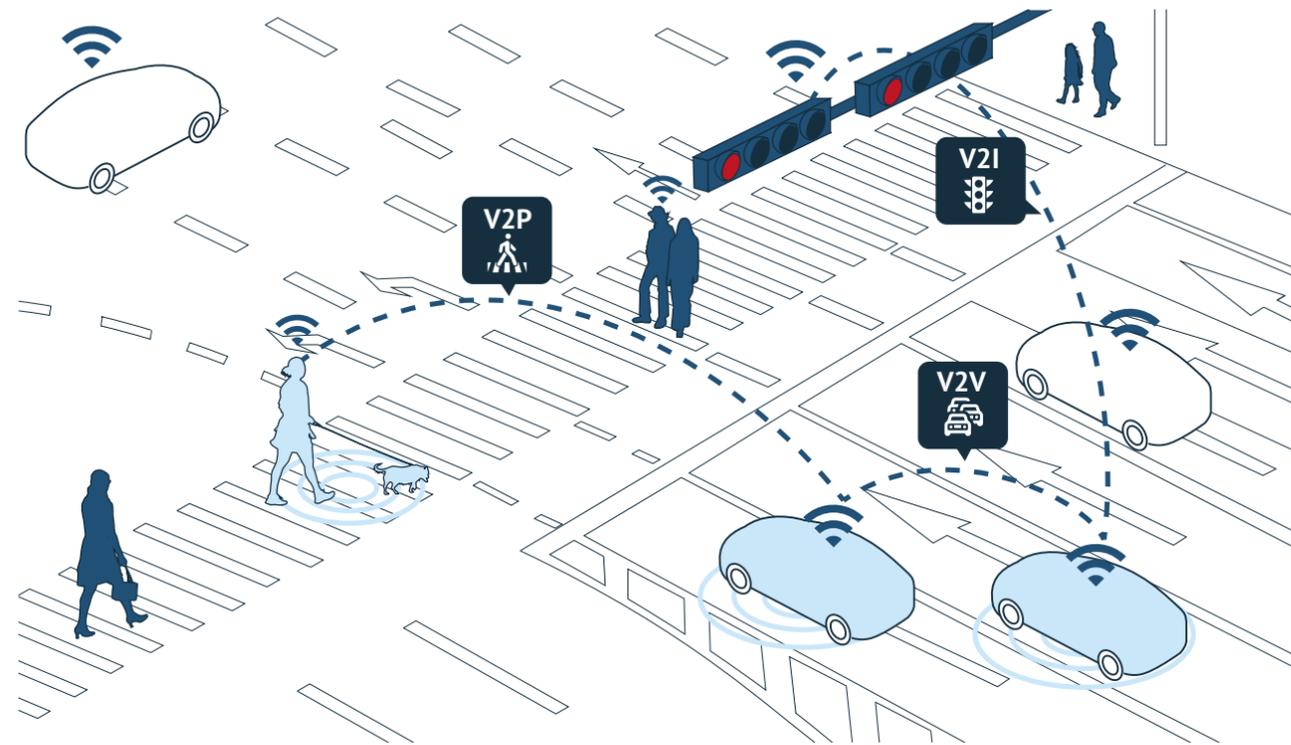
Vehicle Communication

To reach level 5 autonomy in dense urban areas, it is expected that vehicles must be able to communicate not only to other vehicles (V2V) they share the road with but also with infrastructure (V2I), pedestrians (V2P), cyclists (V2C), and more.

For autonomous vehicle OEMs, achieving V2X relies heavily on the investment efforts from governments and technology providers. The rollout of V2V is more closely enabled by

manufacturers who are responsible for the connectivity features and communication between vehicles on the road.

Our previous report provided detail on the two wireless technologies at the heart of V2V: dedicated short-range communications (DSRC) and cellular vehicle-to-everything (C-V2X). The question whether DSRC or C-V2X is the best choice and which will prevail remains within the industry that continues to evolve based on complex business models and regional standards. The split between OEMs regarding which technology to invest in may have negative effects on it reaching critical mass. For it to function effectively, enough vehicles on the road within a 300-meter radius of



The V2X ecosystem

one another must have V2V installed.

Both DSRC and C-V2X technologies operate in the 5.9 GHz band. Although DSRC dominated, especially in the USA, as the standard in the earlier years of Connected Vehicle development up to 2019, in recent years C-V2X has started to be adopted by more and more car makers and transport authorities.

China, in particular, has invested heavily in C-V2X and in an integral part of intelligent transportation, Ford's C-V2X services have been successfully implemented in six cities in China this year. Its C-V2X system has been installed in over 330,000 production vehicles to date, with the cumulative number of users accessing Ford's C-V2X system in China has exceeded 36,000, with over 12,000 actual service users.⁵⁷

In May, 2023, the US Federal Communications Commission (FCC) granted a joint waiver request to deploy cellular Vehicle to Everything (C-V2X) technology in the upper 20 MHz part of the 5.9 GHz band.

European administrations have designated the 5.9 GHz band for use by road Intelligent Transport Systems (ITS). As is common practice in Europe, the spectrum is designated on a technology neutral basis.

C-V2X is also backed by the influential 5G Automotive Association (5GAA), which has 36 automotive members, including some of the largest European, US and Asian OEMs such as Audi, BMW, Ford, GM, Hyundai, Mercedes Benz, Mitsubishi, Nissan, Volkswagen, and Volvo. It also includes leading Chinese car makers such as FAW and SAIC.

Over-the-Air (OTA) updates enable remote software updates for vehicles.⁶⁸ This capability is crucial for ensuring the safety, reliability, and adaptability of AVs as they navigate evolving road conditions and regulatory requirements.⁶⁹

OTA updates facilitate the deployment of critical security updates, safeguarding AVs from emerging cyber threats. Given the potentially catastrophic consequences of a security violation in AVs, the ability to promptly deliver security updates is very important. OTA updates enable manufacturers to respond swiftly to vulnerabilities, mitigating risks and improving the overall security of AVs.

There are two types of OTA updates: firmware over-the-air (FOTA) and software over-the-air (SOTA). SOTA updates are generally used to improve user interfaces and infotainment systems, while FOTA requires advanced technology for communication,

cybersecurity, and memory storage to update.⁷¹⁻⁷⁴

Tesla has long been the leader in this area - using OTA updates to fix small issues such as faulty tail lights to bigger updates that have enabled the Tesla Model 3 to have a quicker 0-60 time now than it had when it was first purchased. Other automakers are rapidly embracing the use of OTA. Recent research shows that installing OTA systems in passenger cars in China increased 31.8% from January to June 2023.

Volkswagen is already offering regular OTA updates for its ID range of BEVs. Hyundai, Kia, and Genesis's next-generation of EV platforms will feature an integrated software controller for deeper integration and upgradeability.

Over the past three years, there have been hugely impactful advances in OTA updates that are paving the way for a future of software-defined vehicles (SDV). Key areas for advancement have been in making the updates faster and more reliable as well as for software developers to create products that OEMs can add quickly to their vehicles.

“The FCC decision to grant a waiver for C-V2X deployment is a major step forward in the efforts of roadway safety. The industry has said C-V2X is ready to deploy, now it is time to deploy.”

Bryan Mulligan, President, Applied Information. May, 2023.

Qualcomm

Qualcomm is one of the companies enabling a software driven future. They have collaborated with automakers and launched the 4th generation Snapdragon Automotive Cockpit Platform in June 2023. The company has introduced the Qualcomm Car-to-Cloud Service for Snapdragon Automotive Cockpit Platforms and Snapdragon Automotive 4G and 5G Platforms. This integrated connected-car service aims to keep vehicle systems up to date, activate features flexibly, and unlock new revenue streams via OTA updates, on-demand feature activation, and pay-as-you-use services.

The service incorporates a Soft SKU capability for field-upgradeable chipsets, allowing for performance boosts, feature upgrades, and regional customization. Additionally, the Car-to-Cloud Service offers actionable analytics for personalized user experiences and supports a secure chipset-based solution for feature management.⁷⁵

Airbiquity

Airbiquity is a prominent provider of OTA update solutions within the automotive sector. In September 2023, they announced their partnership with Tessolve. The two companies have pre-integrated Airbiquity's OTAmatic® software management platform and LOGmatic™ data logging platform with Tessolve's TERA family of devices to provide application gateways that can be easily integrated into vehicles. Combining their individual solutions will reduce the complexity, expense, and time required for original equipment manufacturers (OEMs) to evaluate, develop, and deploy sophisticated connected vehicles that include full-vehicle OTA software updates and flexible data logging.⁷⁶

eSync Alliance

The eSync Alliance Initiative represents a collaborative effort involving multiple companies to advance OTA updates and diagnostics within automotive electronics. At its core, the eSync infrastructure presents a unified architecture, developed with application programming interfaces, to facilitate seamless data exchange between the cloud and end devices. This system enables safeguarding both safety and privacy through robust end-to-end cybersecurity measures and is crucial in the retrieval and management of diagnostic data, while also ensuring that software across various devices is consistently updated and fine-tuned.

In 2022, the eSync Alliance announced the inclusion of Asvin, a cybersecurity and software lifecycle management specialist, as a promoter member. To maintain the integrity of the software supply chain, Asvin has innovated a decentralized blockchain-based solution, employing distributed ledger technology. This approach ensures a solid framework to secure OTA updates and meticulously record all software alterations for both verification and regulatory adherence.

In 2023, the eSync Alliance, alongside Luxoft, a subsidiary of DXC Technology Company, declared Luxoft's new status as an adopter member of the eSync Alliance. With its expertise in the field, Luxoft is well-positioned to assist car manufacturers in staying ahead in the race towards software-defined vehicles. Luxoft perceives the eSync Alliance's commitment to standardizing OTA updates and diagnostic solutions as a crucial step in alleviating the challenges associated with developing software-defined vehicles.

5G Connectivity

5G, the fifth generation of wireless technology, began rolling out in 2019 driven by the need for faster and more reliable wireless connectivity, data-intensive applications and services, and the anticipation of the IoT era, where countless devices and sensors would require low-latency, high-bandwidth connections.

5G's ultra-low latency and high-speed data transmission capabilities are indispensable for enabling real-time communication and data exchange among autonomous vehicles, infrastructure, and cloud-based systems. This facilitates instantaneous decision-making, enhanced situational awareness, and seamless coordination between vehicles and their environment. With 5G, autonomous vehicles can process extensive data from multiple sensors in real-time, significantly improving safety, efficiency, and responsiveness.

It is important to note that companies typically closely guard their latest advancements in this field, which makes it challenging to compile a comprehensive report on the precise evolution of 5G technology with an abundance of technical details. Nevertheless, relying on publicly available information, in this section we explore the advancements on 5G technologies for AV applications.

Innovations in 5G for AV Applications

Between 2020 and 2023, 5G technology has made remarkable strides, currently offering speeds that are up to 100 times faster than its predecessors.⁵⁸ Novel 5G solutions enable quicker software updates directly to vehicles, reducing the necessity for extended service visits. This enhanced connectivity is pivotal in facilitating real-time communication with ultra-low latency between AVs, roadside infrastructure, and other vehicles. These solutions are further characterized by swift response times, with delays under 10 milliseconds.

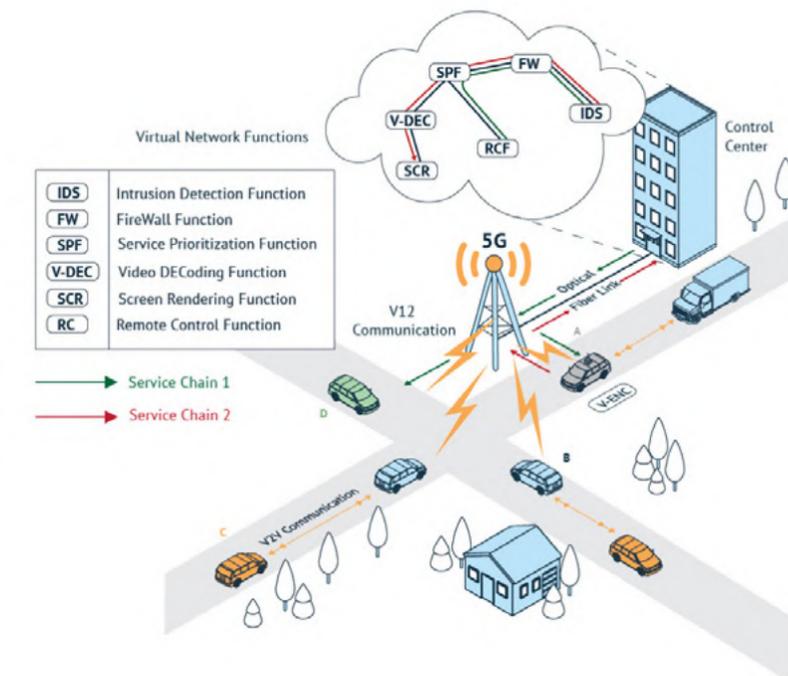
By allowing more efficient utilization of frequencies, 5G accommodates a growing number of simultaneous users while reducing energy consumption.

Furthermore, 5G networks are typically optimized to allocate dedicated slices of bandwidth for specific applications, ensuring the prioritization of safety-critical communications within AVs, even in congested network conditions.

Since 2020, 5G technology has significantly increased its support for Vehicle-to-Everything (V2X) communication, a technology pivotal for enhancing road safety and traffic efficiency, ultimately contributing to accident prevention and saving lives. Specifically, Cellular V2X (C-V2X) enables two-way communication, extends its range, and facilitates the sharing of sensor data via the cloud, all while achieving a remarkable reduction in data transmission delay, measuring less than four milliseconds, a critical factor in congested traffic scenarios.

In 2021, the 5G Automotive Association (5GAA) initiated creating a C-V2X test system for self-driving cars, demonstrating 5G's potential in enabling real-time vehicle communication for improved safety. In 2023, Qualcomm Technologies' collaboration with Jaguar Land Rover (JLR) aims to integrate the Snapdragon auto connectivity platform into JLR's luxury vehicles, incorporating 5G, Wi-Fi, and C-V2X technologies. These enhancements promise improved safety and the introduction of multimedia streaming, cloud gaming, and precise positioning.

Vehicles equipped with the Snapdragon Auto 5G Modem-RF are expected to be available by 2025, marking a significant step forward in the automotive industry's integration of 5G technology.



Example of a 5G network slice encompassing autonomous vehicle navigation. Image credit: Qu, L. et al.

5G has also enabled the shift of AI capabilities from the vehicle to mobile edge computing (MEC), reducing the need for onboard AI. The MEC and V2X software platforms identify the pedestrian and vehicle, sending a location-based alert and issuing a visual warning to the driver. 5G technology has also been important for developing digital twins, which play a crucial role in planning, asset monitoring, and predictive analytics.

Future Connectivity Standards

The future of AVs is poised to embrace the revolutionary capabilities of novel 6G and 7G technologies. Currently, there is active exploration and discussion surrounding the potential integration of these advanced wireless communication generations. Potential benefits include heightened connectivity, accelerated data speeds, reduced latency, and enhanced reliability.

While these advancements hold significant promise, concrete implementations and standardized frameworks are in the nascent stages of development. The overarching goal is to harness the power of these future wireless technologies to facilitate real-time communication, seamless data exchange between vehicles and infrastructure, and usher in transformative advancements in AV capabilities. Stay tuned for further developments as the industry progresses towards this exciting future.

Security

The expanding digital footprint of autonomous vehicles, coupled with the incorporation of artificial intelligence capabilities, has broadened the potential for cyber vulnerabilities. From an attacker's perspective, an autonomous driving system consists of three layers: Sensor Layer, Communication Layer, and Control Layer. The sensor layer includes sensors that continuously monitor vehicle dynamics and the environment, but are vulnerable to eavesdropping, jamming, and spoofing attacks. The communication layer includes both near-field and far-field communications to enable communication between other edge sensors in the vicinity and remote edge data centers. This layer is vulnerable to 'man-in-the-middle' and Sybil attacks. The control layer at the top of the hierarchy enables autonomous driving system functions such as automating a vehicle's speed, braking, and steering. Attacks on the sensor and communication layers can propagate upward, compromising functionality and compromising the security of the control layer.⁶⁴

Cybersecurity threats have been documented by gray or white hat hackers identifying cybersecurity threats in advanced driver assistance features available in passenger cars. Such as researchers from Keen Security Labs in China who in 2022 demonstrated a couple of exploits through a camera system in a Tesla Model S.⁶⁵ Other researchers have exposed that DL models exploited in AVs to mimic human cognitive capabilities are not entirely secure and are highly vulnerable to attacks that might jeopardize the normal operation of AVs and provide unmodelled threats and unanticipated challenges to safety.

Addressing the rising potential of cyberattacks vehicles, security experts are shifting their focus towards proactive defense strategies. A cornerstone of this approach is the concept of „security by design.“ This philosophy emphasizes the integration of security features directly into the foundational design of technological systems, rather than treating them as secondary additions or retrofits. This proactive stance ensures that security considerations are woven into the fabric of the technology from its inception.

The most important security measures that can be implemented as part of security by design include encryption of data transmissions, authentication of communication participants, regular updating of software and firmware, and the use of intrusion detection prevention systems (IDPS).

Key advancements in IDPS for autonomous driving include

Machine Learning and AI Integration: Companies are utilizing machine learning and AI algorithms to enhance the accuracy and efficiency of intrusion detection. These systems can learn from historical data and adapt to new attack vectors, making them more resilient against evolving threats.

Anomaly Detection Techniques: AV IDPS utilize sophisticated anomaly detection techniques to identify deviations from expected behavior. These techniques enable the system to detect novel attacks that might not match known attack patterns.

Real-time Threat Analysis: IDPS for AVs operate in real-time, analyzing data streams from various sensors and vehicle components to detect and respond to threats as they occur.

Collaborative Threat Intelligence: Some solutions incorporate shared threat intelligence databases, allowing vehicles to learn from each other's experiences and rapidly respond to emerging threats collectively.

This table provides an overview of some of the companies, their products, and how these are being utilized in the market, along with the types of users who are implementing these cybersecurity solutions in the autonomous vehicle sector.

Company	Products/Research	Users	Usage
Argus Cyber Security	Argus Connectivity Protection, Argus Lifespan Protection	Automotive OEMs, Tier 1 suppliers	In various vehicle architectures including ECUs, telematics, infotainment systems
Symantec (now part of Broadcom)	Symantec Integrated Cyber Defense Platform	Automotive manufacturers, suppliers	For comprehensive threat protection and management in automotive systems
Harman	Harman's ECUSHIELD, TCUSHIELD	Automotive OEMs, telematics units	Securing in-vehicle and telematics systems against cyber threats
Cisco	Cisco's automotive cybersecurity solutions	Connected vehicle manufacturers, infrastructure providers	Integrating cybersecurity in connected vehicle networks and infrastructure

Securing AVs with Blockchain

Blockchain technology offers several ways to enhance security in connected Autonomous Vehicle (AV) services. Its unique characteristics make it a promising solution for some of the key challenges in this domain including:

Data Integrity and Traceability: Blockchain's inherent property of immutability ensures that once data is recorded, it cannot be altered without detection. Such data might include travel logs, sensor readings, or maintenance records. This traceability is essential for diagnosing issues, resolving liability questions in accidents, and preventing tampering.

Secure Communication: Blockchain can facilitate secure, decentralized communication between vehicles and infrastructure (V2X). By using blockchain's distributed ledger technology, AVs can validate and trust messages received from other vehicles or infrastructure without needing a central authority. This is particularly useful for preventing spoofing attacks where malicious entities might send false information to AVs.

Decentralized Operations: Unlike traditional centralized networks, blockchain operates on a decentralized network. This decentralization makes the system more resilient to cyberattacks, as there is no single point of failure. In the context of AVs, this could mean a more robust network for vehicle communication and coordination, less susceptible to large-scale attacks.

Identity Management and Authentication: Blockchain can be used to securely manage digital identities in the

AV ecosystem. By using cryptographic keys for identity verification, it ensures that only authorized devices, vehicles, and infrastructure can communicate with each other. This can prevent unauthorized access and control of vehicle systems.

Smart Contracts for Automated Transactions: AVs can use blockchain-based smart contracts for automated, secure, and transparent transactions. This is particularly relevant for services like automated toll payments, parking fees, or even peer-to-peer energy transactions in the case of electric AVs.

Supply Chain Transparency: Blockchain can also enhance the security of the AV supply chain. By tracking the production, shipment, and installation of vehicle parts, blockchain can ensure authenticity and prevent counterfeit parts from being used, which could be a security risk.

Data Sharing and Privacy: Blockchain enables secure and selective data sharing. AVs generate vast amounts of data, and blockchain can facilitate the sharing of this data with third parties (like traffic management systems or other vehicles) in a way that preserves user privacy and data security.

Since 2020, numerous research papers have made significant contributions to the field of intelligent vehicle (IV) communication by harnessing blockchain technology, each with distinct areas of focus. Some studies have concentrated on establishing IV communication systems that place a high premium on security and reliability.

Diverse research directions within the domain of human safety and the aftermath of accidents have also

been explored. One example is a reward-based system underpinned by crypto IV-TP, emphasizing the maintenance of unambiguous accident records. Furthermore, we can see innovative Multi-Agent AIM (MAAIM) systems, which adeptly manages the safe navigation of vehicles through intersections using V2I/I2V communication bolstered by blockchain technology.

Another line of research focuses on the secure real-time exchange of information among connected and autonomous vehicles. This endeavor is critical, particularly in light of emerging cyber threats. Cyberattacks, such as Denial-of-Service (DoS) attacks, can pose a substantial challenge to AV systems. These attacks may involve flooding the system with spurious requests, jeopardizing its functioning. Furthermore, it improves the overall security of IoT devices and positively impacts both the performance and scalability of AV services.

Lastly, localized Peer-to-Peer (P2P) electricity trading models have also been designed for Plug-in Hybrid Electric Vehicles (PHEVs) operating within smart grids. This model not only seeks to optimize costs but also enhances trustability and social welfare. By implementing an iterative double auction mechanism in localized P2P electricity trading systems, auctioneers are able to bid prices, ensuring transaction security, privacy protection, user satisfaction, and cost minimization or the attainment of the best prices. This multifaceted body of research underscores the diverse array of challenges and opportunities in the burgeoning field of IV communication within the context of blockchain technology.⁶⁶

Companies Developing Security Solutions for AVs

ETAS

ETAS, in response to the increasing connectivity and automation of vehicles, has developed the ESCRYP T Intrusion Detection and Prevention Solution (IDPS) for connected fleets. This solution aims to monitor incidents and risks throughout the entire life cycle of vehicle fleets, complying with regulations such as UN Regulation 155 and ISO/SAE 21434. The ESCRYP T IDPS offers a holistic approach, ensuring continuous security improvements, permanent monitoring, and incident response.

The components of this end-to-end solution include the ESCRYP T Intrusion Detection Systems, Automotive Firewall (ESCRYP T CysurGATE), Threat Detection and Threat Intelligence (ESCRYP T Threat), and the monitoring backend product ESCRYP T CysurGUARD. Additionally, ETAS provides a Vehicle Security Operations Center (SOC) as a managed security service, integrating IT security expertise with automotive cybersecurity know-how to address the evolving threat landscape. The benefits of this solution include tailored one-stop delivery for vehicle fleets, operational excellence, global coverage, and openness to various in-vehicle Intrusion Detection Systems.⁶⁷

C2A Security

C2A Security specializes in securing in-vehicle communication and diagnostics systems, offering solutions that prevent unauthorized access and mitigate cyber risks in AVs. C2A Security delivers automated cybersecurity solutions that empower the evolution of connected, autonomous, and electric

mobility. At the heart of C2A Security's offerings is their premier product, EVSec, a DevSecOps platform. This innovative solution equips automotive companies to maintain their competitive edge and enhance customer value in the era of software-defined vehicles. EVSec covers the full security lifecycle, spanning from development to operations and back. By employing EVSec, C2A's clientele gains access to effective and streamlined cybersecurity processes, enabling the efficient management of software on a large scale. This approach not only addresses the scarcity of cybersecurity experts but also ensures compliance with emerging regulations through automated means.⁶⁸

It is important to emphasize that Valeo and C2A Security have formed a strategic collaboration to strengthen cybersecurity in Valeo's products, addressing the evolving landscape of software-defined vehicles and emerging automotive cyber regulations. The partnership aims to address the demand for efficient and streamlined cybersecurity solutions in the industry. C2A Security's expertise in automated cybersecurity is set to empower Valeo to implement advanced security measures while fostering innovation.⁶⁹

Karamba Security

In May 2023, Karamba Security secured a production agreement for its XGuard Host Intrusion Detection and Prevention software. XGuard, with its continuous runtime integrity checks, intrusion detection, prevention capabilities, and reporting to the OEM's security operations center, addresses the growing emphasis on cybersecurity readiness among OEMs in line with UN R155 and emerging Chinese automotive cybersecurity regulations.

Praised for its in-depth security, simple integration, and minimal performance impact, Karamba's solution ensures compliance with regulations and enhances the security posture of vehicles. Additionally, Karamba provides deterministic and always-on security solutions for autonomous vehicles, utilizing Automotive Control Flow Integrity (CFI) to prevent cyberattacks without compromising performance. XGuard and SafeCAN offer comprehensive protection against external and in-vehicle network attacks, seamlessly integrating security into the ECU image build.

Key technical features include embedded XGuard agents with negligible performance overhead, unsupervised machine learning for anomaly detection, and compliance with ISO21434 and UNECE R155 cybersecurity standards. This approach ensures a self-defending vehicle with minimal performance impact.

SPONSOR INTERVIEW



Christian Thiele

Director of Global Vehicle Standards at SAE International

Driving Global Standards: Insights from SAE International

What is SAE?

Christian Thiele: SAE International has been around for about 118 years, our primary focus is dealing with the development of standardization and selling and getting those standards out to the industry. Recognizing that our mission is to advance mobility, knowledge, and solutions for the benefit of humanity, with the vision to connect and educate mobility professionals to enable a safe, clean, and accessible mobility solution at the end of the day, we do this through mutual forums. And by that we enable these mutual forms to develop consensus-based global standards for the global mobility industry.

We are the largest organization that drives mobility standards. But in order to deal with that, we also have a foundation and we also do STEM research, to help develop and grow through learning, through professional development, and pre-professional development, driving people to engage through engineering technology. Basically, fill those coffers for future committee members and future engineers who help these consensus-based standards being developed and produced.

Thanks for the overview. Then when it comes to autonomous cars, you've probably answered this question in part already but how is SAE involved in autonomous cars?

Christian Thiele: Let's look at it this way. Right now, we're not at the autonomous phase. Let's look at automated driving, and recognizing and understanding the automated space. We have specifically through our J3016 identified the levels of automation and clearly, level five and beyond is when you get to a level where you could call it autonomous.

But at the end of the day, what our focus is, is helping drive those standards and develop those standards. To allow interoperability and harmonisation, especially the communication side of how automated vehicles are managed.

Automated driving, ultimately from a vehicle and driver perspective, is to make certain that active safety standards that are built into a vehicle, i.e. the automatic braking, lane change sensing, holding steering wheel position of the car in the lane so it doesn't leave the lane, etc. These are technologies and spaces that we have helped develop in the industry, and helped through our standard organization bodies, building those standards that define what that needs to be.

What are some of the key challenges your members are facing particularly with AV?

The key, especially from a technology point of view, is getting things that are working, to scale and interoperability. This is what we tried to do through our harmonization and through defining those standards for those communication protocols that need to happen, which allow everybody to communicate at one frequency, at one time. It's not English to Chinese; it's everyone speaking English, so to speak, to put it in layman's terms.

Okay, perfect. And then talking about the organization in a more general capacity. What are some of the benefits to your members of being in SAE and the adherence to these standards?

Let's look at what standardization does for a company and organization itself. First, you reduce costs and design development, because you are convening a large group of industry experts that come together to help better define, narrow, and develop what standards we need to follow and to make design and development easier on the individual corporations and companies. This makes engineering easier and it reduces the cost. It also increases performance as it permits a common interface. Increased productivity and processes enable companies to become more effective and efficient at what they do as a corporation.

So ultimately, what does this do at the end of the day? It helps to enhance safety, create a common language out there for everybody to communicate to, and facilitates throughput through regulations. It harmonizes the global marketplace.

Standards ultimately give compatibility, consistent quality product, regulatory compliance, clear expectations, and consistent product performance. Everybody understands what needs to be when, where and how. It also allows for efficient procurement, which is vitally critical for organizations and companies to be able to buy and procure products.

These reasons show why the SAE and the standards bodies organizations are vitally critical.

Then how do you actually create global standards when regulations requirements vary so much by country?

Yeah, so, what we do is we work on a regional, national, and international space. Standards by themselves are not the finding. The right standards give you a direction of what is perhaps seen as the best technical information out there.

We support harmonization through the UN. For example, we sit as a consultant on a consultative body. Where we contribute expertise on dealing with communication protocol and connected vehicle protocols. We helped derive some of those standards that ultimately will be implemented at a local government level.

How different are the SAE standards for autonomous vehicles versus the current generation of vehicles?

Let's understand two things. First, before, the car was a self-contained environment. At the end of the day, it never communicated with the outside environment. The person or thing that was communicating was you, the individual driving the vehicle who was seeing and hearing etc. And you would make that vehicle go where it needed to go. Now you have systems that are going to define where, when, and how to best engage that vehicle under certain circumstances. And that's where the challenge is. How much confidence do we have from a security point of view to ensure that the systems are secure, without being hacked or compromised, through other means? Now, even EV vehicles recognize they're plugging in and charging. Anytime you plug in the vehicle, something happens as it relates to communication between the vehicle and the outside world. And there are threats and risks there.

So in your opinion, where do you think we are with autonomous vehicles? And what's your vision of an autonomous future?

I definitely see an opportunity. I don't think we're there yet with a fully automated vehicle. I think level one or two are pretty sound and robust. Level three and beyond that, that's where it becomes challenging and I think in the next five to 10 years, you will see major technology advancements allowing for reliability and capability to execute to a certain level that is acceptable. You don't want a braking system working 60% of the time, you'd like it to be in the 99 percentile, recognizing and understanding that these things will help and benefit the occupants in the vehicles and the drivers themselves. We had over 43,000 deaths last year in the US related to automotive mobility related deaths. That is a frighteningly large number and we need to do whatever we can do from a technology point of view, to advance these vehicles to better utilize technology to better enable automated driving down the road.

Thank you. How do you think AVs can contribute to society? I think you've really touched on it there in terms of reducing the number of deaths and serious injuries.

We need to acknowledge the ongoing revisions to the J3016, which is the standard for defining levels of automation in vehicles. It's crucial to consider human factors in

this context. From the perspective of distracted driving, it's important to recognize the potential benefits of automated and autonomous vehicles. These technologies can significantly aid in addressing distracted driving issues.

Currently, we are exploring technologies that are already available. For instance, in Europe, every new vehicle will be equipped with Driver Management Systems (DMS). These systems, which include vision systems and driver monitoring capabilities, focus on tracking the driver's head and eye positions. This is a key step in enhancing safety through DMS.

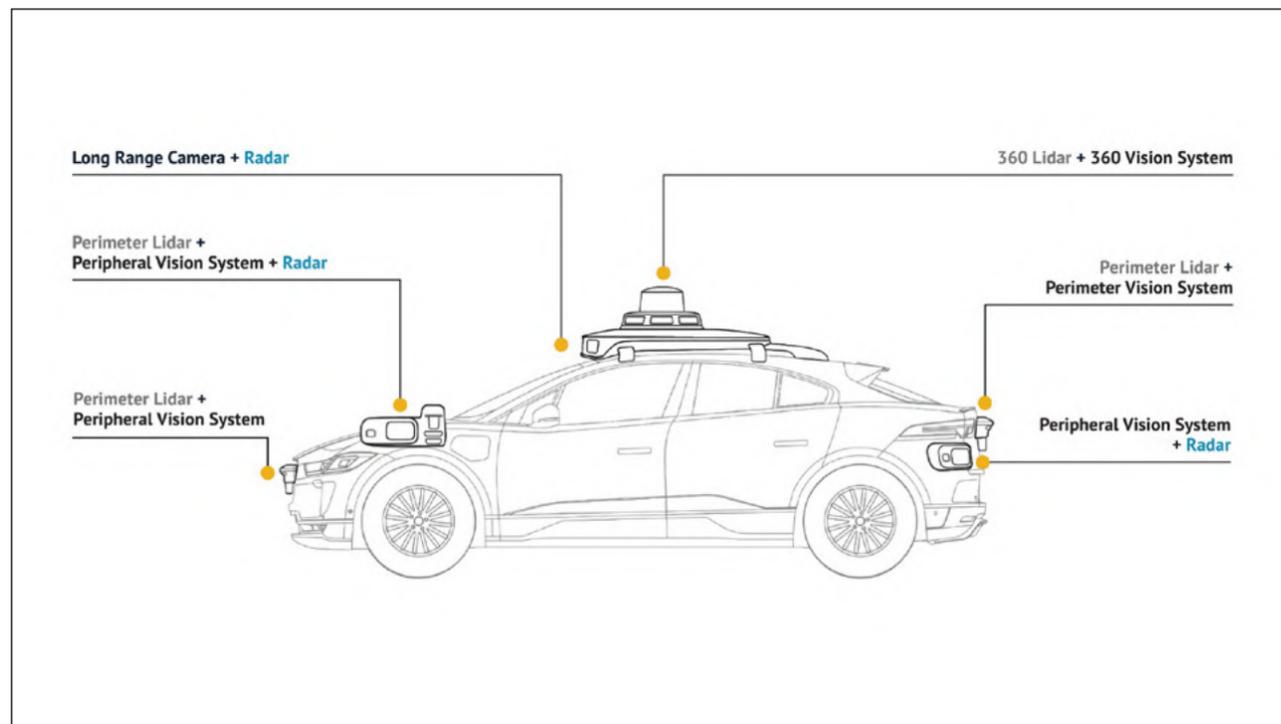
It's essential to always be aware of the driver's actions, particularly the position of their hands. Implementing these technologies immediately can help drivers stay focused on driving rather than being distracted by other activities

Autonomous Vehicle Tech Stack Review

In this chapter, we delve into the current status of prominent autonomous vehicle manufacturers, shedding light on their advancements, achievements, and strategic directions. As these industry leaders push the boundaries of AV technology, they play a pivotal role in shaping the future of transportation.

This overview provides insights into the latest developments and showcases how Waymo, Tesla, Cruise, and Volvo are navigating the complex journey towards fully autonomous vehicles. We have chosen to focus on these four, as they represent a diverse range of approaches and technologies in the autonomous vehicle space and all share a significant public amount of technical information which enables us to make this comparison meaningful.

Company	Cameras	RADAR	LiDAR	AI	Autonomous vehicles
Waymo	Waymo's autonomous vehicles use a combination of high-resolution cameras, but the exact number varies by model.	Uses multiple RADAR sensors for a 360° view; specifics are proprietary.	High-resolution LiDARs, including a rooftop dome LiDAR, for detailed environmental mapping.	Waymo's AI is built in-house, leveraging Google's expertise in machine learning. They use TensorFlow, a powerful AI framework developed by Google.	Waymo One (Ride-hailing service using Jaguar I-PACE and others)
Tesla	Tesla vehicles, especially those equipped with the latest Autopilot and FSD features, use 8 cameras for 360° coverage.	Primarily uses a front-facing radar; Tesla is moving towards a camera-focused system, reducing radar reliance.	Does not use LiDAR, focusing on a vision-based system using cameras.	Tesla's AI is also developed in-house, focused on vision-based machine learning. They've developed their own AI chip for processing.	Model S, Model 3, Model X, Model Y (All equipped with Autopilot and FSD capabilities)
Cruise	Cruise's autonomous vehicles utilize a suite of high-resolution cameras; the exact count is not publicly specified.	Multiple RADAR sensors for comprehensive coverage; specifics are not fully disclosed.	Equipped with top-mounted LiDARs for high-accuracy mapping and object detection.	Cruise, being part of GM, might utilize GM's resources for AI development. They also collaborate with Honda, which could influence their AI technology.	Cruise Origin (Purpose-built autonomous vehicle)
Volvo	Volvo's autonomous driving systems are equipped with multiple cameras, but the exact number is model-dependent.	Employs several RADAR sensors, including front and rear, for enhanced environmental perception.	Incorporating LiDAR in future models; specifics on types and numbers are under development.	Volvo collaborates with companies like NVIDIA for AI technology, utilizing NVIDIA's DRIVE platform for autonomous driving solutions.	XC90 (Pilot Assist system), Future fully autonomous models under development



5th-generation Waymo Driver.
Image credit: Waymo

Waymo

Waymo, a subsidiary of Alphabet (Google's parent company), started research on autonomous vehicles in 2009. In October 2020, it became the first robotaxi service to offer service to the public without safety drivers in the vehicle.

Waymo's 5th-generation driver is a combination of hardware, software, and compute designed to navigate complex driving environments. It relies on a comprehensive sensor suite, including high-resolution 360-degree LiDAR with a 300-meter range, cameras with overlapping fields of view for detailed imaging, and a newly designed imaging radar system that provides high resolution

even in adverse weather conditions. The technology was developed from over 20 million self-driven miles and 10 billion simulated miles. In the last three years, Waymo has focused on scalable production, reducing costs while increasing sensor capabilities.

Since 2018, Waymo has been working with Jaguar Land Rover to create the world's first premium electric fully self-driving vehicle. Its latest iteration is currently being tested on public roads in the US.

Camera Array and Coverage

Currently, Waymo's enhanced vision system integrates high-dynamic range cameras with exceptional thermal stability to deliver crisp, detailed images across extreme automotive

temperature conditions. The long-range and 360-degree cameras extend vision capabilities beyond 500 meters, sharpening the detection of critical elements like pedestrians and road signs. Moreover, custom-designed lenses and meticulous optomechanical construction elevate these cameras beyond current standards. In synergy with perimeter LiDAR sensors, the perimeter vision system grants additional contextual data, improving object identification.

The peripheral vision system mitigates blind spots, ensuring safer maneuvering around large vehicles. This network of cameras empowers the Waymo Driver with unprecedented decision-making clarity and speed.



Camera view of Waymo's Jaguar I-PACE vehicle.
Image credit: Waymo

LiDAR

The 5th-generation Waymo Driver employs a sophisticated overlapping LiDAR system. Its core LiDAR creates a 3D picture of the vehicle's surroundings that can discern the size and distance of objects around it. This system is effective over 300 meters, allowing it to identify objects in various lighting conditions, from bright sunlight to moonless nights.

The 360 LiDAR system offers a comprehensive view that can distinguish minute details, such as opening a car door from a block away, aiding in navigating complex city environments. Moreover, it also enables Waymo's trucks to detect road debris from a considerable distance, allowing for timely and safe maneuvering on highways.⁷²

Waymo's perimeter LiDARs, placed at strategic points around the vehicle, afford a wide field of view for detecting proximity objects. This feature is critical for navigating tight spaces in heavy traffic and monitoring potential

blind spots caused by the terrain. Altogether, these LiDAR systems represent a significant upgrade from previous iterations, improving the Waymo Driver's ability to handle more challenging driving scenarios.

RADAR

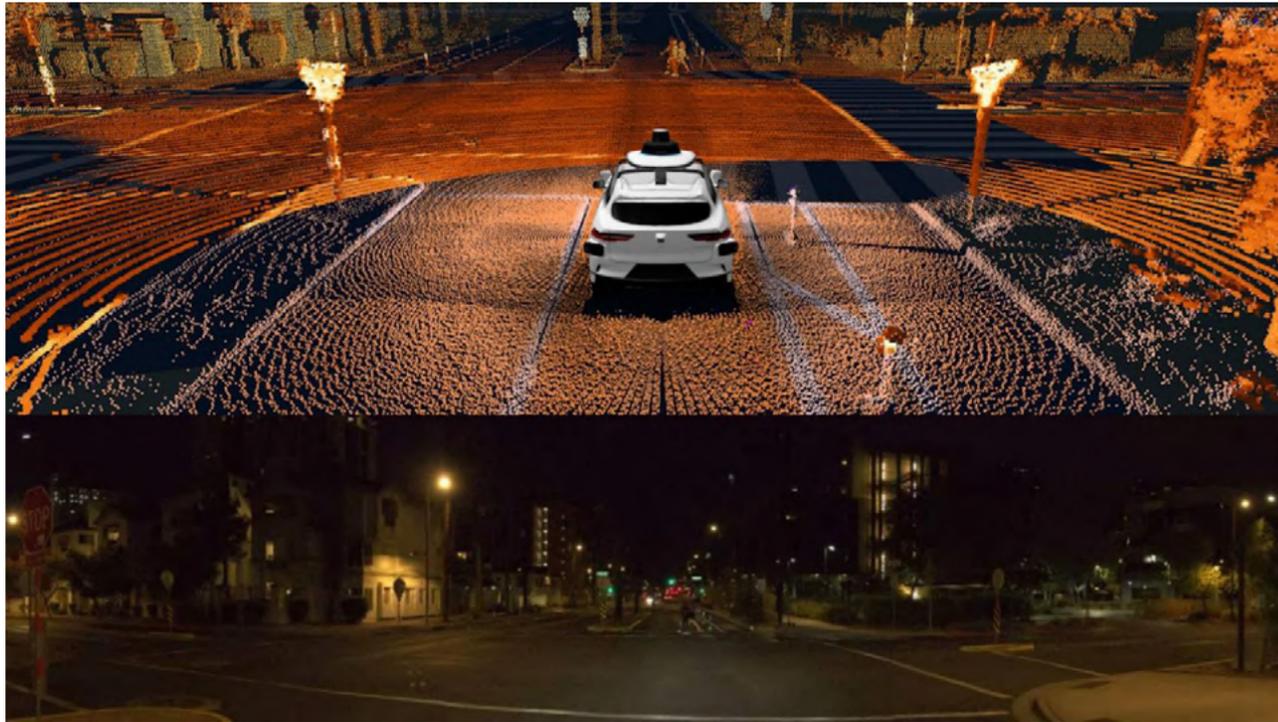
Waymo's sensor fusion is defined by the integration of LiDAR, camera, and RADAR technologies. LiDAR constructs a 3D outline of objects, while cameras contextualize the vehicle's surroundings. The radar, with its swift velocity measurement, excels in challenging weather, offering a consistent panoramic view. The 5th-generation radar architecture contains an imaging radar system that enhances resolution and range. It is engineered to cover vast distances, such as detecting a distant motorcyclist, providing the Waymo Driver with improved reaction time and ensuring a smoother journey for passengers.^{71,73}

Artificial Intelligence

Within its AVs, Waymo integrates AI for diverse functions, including object

detection, lane identification, and obstacle evasion. The company harnesses AI to create an environment mapping and route planning system for its autonomous fleet.⁷⁵ In addition, Waymo quantifies uncertainty in sensor data using probabilistic methods, enabling event probabilities like pedestrian crossing calculations. Moreover, data augmentation is harnessed to expand training data artificially, diminishing the impact of noise. The company also enhances accuracy by using ensemble learning and training distinct autonomous perception models.

Waymo employs a hybrid strategy, blending deep learning with hand-crafted features to enhance their feature extraction process. Their DL models are educated using an extensive dataset collected from their self-driving vehicles, encompassing images, LiDAR, and RADAR data. These models learn to identify vital driving-related attributes, such as object shapes, distances, and velocities.



Waymo smart LiDAR solutions.
Image credit: Waymo

Furthermore, the company incorporates handcrafted features within its ML models. In this case, humans design these attributes based on their knowledge of the environment and driving dynamics. As an illustration, they may incorporate features like sun position, road color, and the presence of traffic signage.

Simulation and Testing

Waymo's engineering team deploys simulations to expose autonomous driving systems to collision scenarios. This method refines algorithms and responses without risking actual vehicles. Accumulating over 20 billion miles in simulation, Waymo identifies challenging situations autonomous cars might face on roads. This ongoing practice, involving simulations adjusted with accurate data and

virtual scenario creation, enhances the autonomous driving software.^{76,77}

Commercial Partnerships

In 2022, Waymo and Uber partnered to introduce driverless cars to Uber's platform, allowing customers to use a specific number of Waymo's AVs for rides and deliveries within a defined area.^{78,79}

Tesla

Founded in 2003 by a group of engineers with the mission of proving that electric cars could be better than gasoline-powered cars, Tesla, Inc. has grown to become the most recognizable name in the electric vehicle (EV) market but also in the frontier of autonomous driving technology. Headquartered in Palo Alto, California, Tesla's name pays homage to Nikola Tesla, the renowned inventor and electrical engineer.

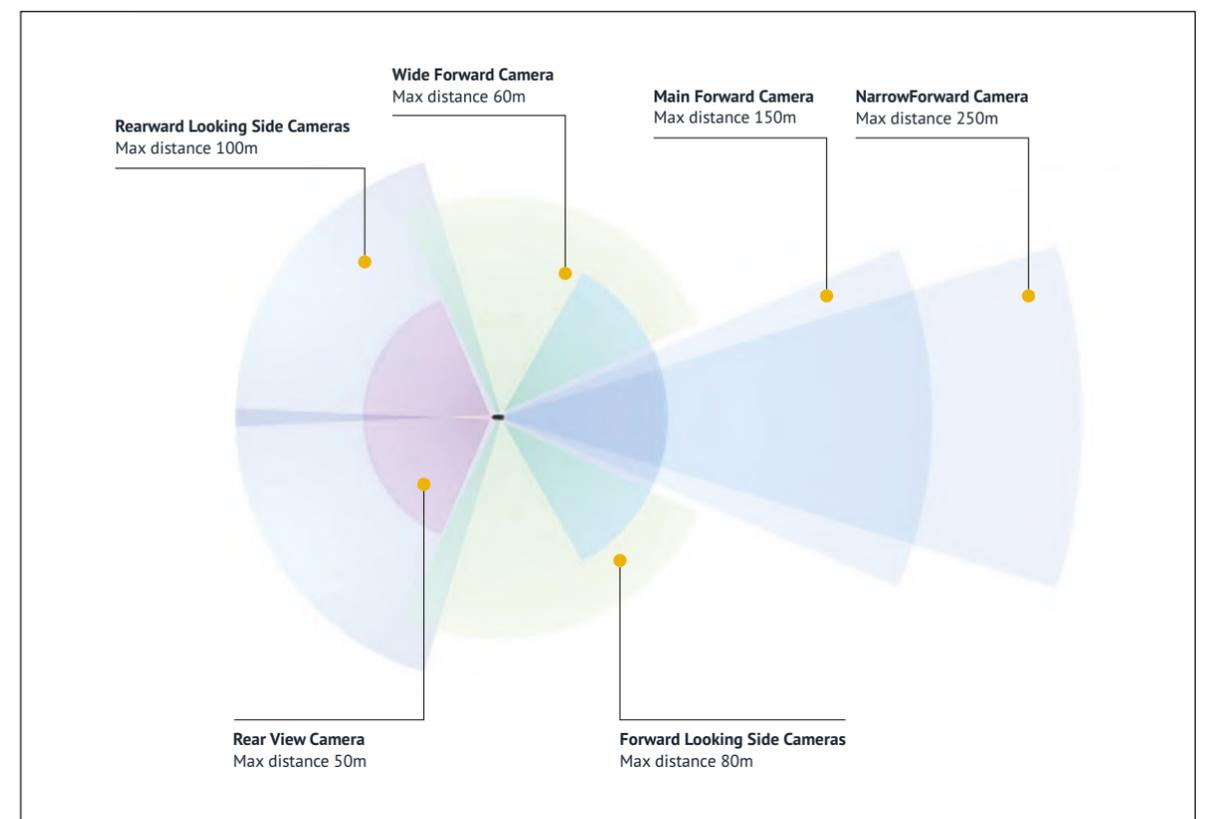
Camera Array and Coverage

Tesla's adoption of cameras began in 2021, when the company transitioned North American production of the

Model 3 and Model Y to a pure vision model, removing the RADAR sensors.⁸⁰ However, the most recent Model X HW4 has a new Tesla-built RADAR equipped. The Model 3 and Model Y, built for the European and Middle Eastern markets, use the internally developed camera-based Tesla Vision, relying solely on Tesla's advanced suite of cameras and neural net processing to deliver Autopilot and related features.

Tesla Vision leverages the capabilities of neural networks and machine learning to interpret visual data, a technique similar to the human visual system. This approach relies mainly on camera inputs, eschewing other

sensor modalities commonly used in autonomous driving systems, such as LiDAR. The Tesla Vision system utilizes 8 external cameras, providing 360-degree visibility around the vehicle at distances of up to 250 meters. These cameras are divided into three categories based on their field of view: main, wide, and narrow. The main front-facing camera is responsible for detecting objects directly ahead of the vehicle, the wide-angle cameras assist with peripheral vision and short-range data, and the narrow-angle cameras focus on distant objects, enabling early recognition of fast-approaching vehicles and other hazards.



Coverage zones of Tesla's car cameras.
Image credit: Armstrong, K.

In 2022, the company began removing ultrasonic sensors from their vehicles, replacing them with its vision-based occupancy network, currently used in Full Self-Driving (FSD).⁸²

Data Processing and Neural Network Architecture

In 2019, Tesla unveiled a proprietary AI-driven hardware platform, Hardware 3.0 or AP3, which is the foundation for its Full Self-Driving (FSD) suite. Recently, since May 2023, Hardware 4.0 or HW4 has been used in Teslas. HW4 uses a RADAR named „Phoenix” that operates in the 76-77 GHz spectrum and supports three sensing modes. The advanced HD Synthetic Aperture Radar (SAR) system improves Tesla’s situational comprehension, surpassing the clarity provided by optical systems. This innovative RADAR technology is designed to augment the precision of Tesla’s autonomous navigation features. Its ability to deliver superior performance in low-visibility conditions such as nocturnal settings, fog, precipitation, or snowy landscapes significantly bolsters the safety and reliability of the vehicles’ self-driving functions.

This onboard processing unit is equipped with a powerful neural network accelerator capable of performing trillions of operations per second. The neural networks employed by Tesla are trained on vast datasets collected from the fleet, encompassing diverse driving conditions and scenarios.

These networks are designed to perform complex visual recognition tasks such as identifying lane lines, traffic signals, road signs, and obstacles. They can make temporal associations across frames, which is critical for under-

standing the dynamics of the driving environment, such as the trajectory of moving objects.

Tesla’s neural networks are trained in PyTorch using real-world and simulated data gathered from their vehicles. This approach strongly emphasizes feature extraction directly from visual data, making the system reliant on robust image-based feature representations. Tesla’s preprocessing techniques include data augmentation, which involves introducing various transformations to the training data, enhancing the model’s ability to generalize to different scenarios.^{83,84}

Visual Perception and Decision-Making

Tesla Vision’s algorithms process the camera feeds to create a coherent picture of the environment around the vehicle. They include detecting and classifying various elements like vehicles, pedestrians, cyclists, and static objects. The system then uses this information to make real-time driving decisions, such as steering, braking, and accelerating, aiming to mimic an attentive and skilled human driver.

OTA

In 2020, Tesla provided updates for its Autopilot self-driving system, improving its capabilities, and resolving problems.⁸⁵ Tesla’s software integration allows it to introduce updates that affect various aspects of the vehicle, including multimedia, performance, safety, and even new features like in-car gaming and streaming video.⁸⁶

Continuous Improvement and Fleet Learning

As Tesla Vision collects data, the neural networks are continually refined and updated, which Tesla deploys to

its vehicles through OTA software updates. This process results in a progressively more capable and robust autonomous driving system.

Tesla Vision’s reliance on cameras has been a subject of debate in the autonomous vehicle industry. Cameras can be affected by environmental factors such as lighting conditions, weather, and obstructions. However, Tesla asserts that the adaptability and advancement of its neural networks can overcome these challenges, and the continuous learning loop allows the system to adapt to new situations that it may not have encountered before.

Cruise

Cruise started developing an autonomous on-demand feature in 2013. In 2016, they were acquired by General Motors (GM). The partnership has combined GM’s resources as a global automotive leader with Cruise’s proficiency in advanced software algorithms, sensor fusion, and machine learning.

The latest Ultra Cruise driver-assist system is expected to be included in the ultra-luxury Cadillac Celestiq in 2024. The system includes LiDAR and several other sensor technologies, enabling hands-free driving and covering 95% of driving maneuvers.⁸⁷

Camera Array and Coverage

Cruise’s camera technology forms part of a complex sensor system, including LiDAR, RADAR, and GPS, which collectively provide a comprehensive perception of the vehicle’s environment. The bespoke Sensor Placement Tool ensures optimal sensor placement on the Cruise Origin, providing 360-degree coverage for detecting other road users and obstacles. The hardware-accurate CAD-based model allows for precise sensor positioning,

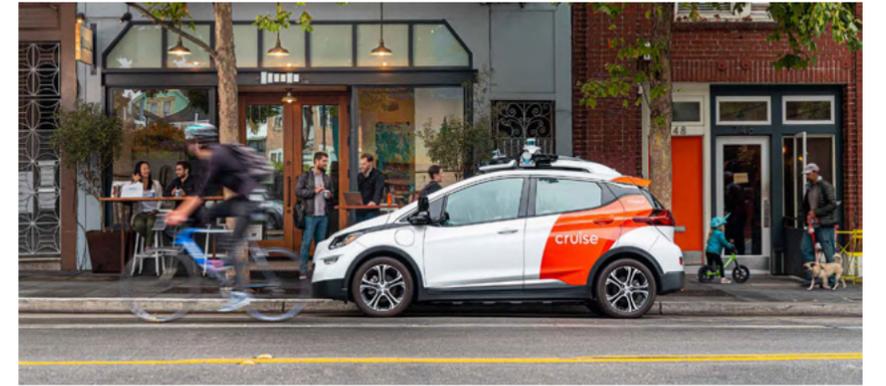


Photo of a Cruise car parked on the street. Image credit: Cruise

avoiding potential occlusions and enabling the testing of various camera configurations for an unobstructed field of view.

LiDAR

Cruise’s autonomous vehicles are equipped with LiDAR sensors that contribute to the 360-degree overlapping sensor coverage, which is vital for the safe maneuvering of the Cruise Origin. The LiDAR system’s point cloud data, which captures the distribution and intensity of the light reflections, is processed through advanced algorithms, allowing Cruise vehicles to identify objects and their movements with centimeter-level precision.

This technology is also pivotal in Cruise’s redundancy and safety mechanisms, ensuring that the vehicle can continue to operate safely even in the unlikely event of a sensor failure. Additionally, the simulations used to accelerate sensor development at Cruise include evaluating the LiDAR’s range and field of view, ensuring optimal sensor placement and calibration for reliable navigation in various driving conditions.

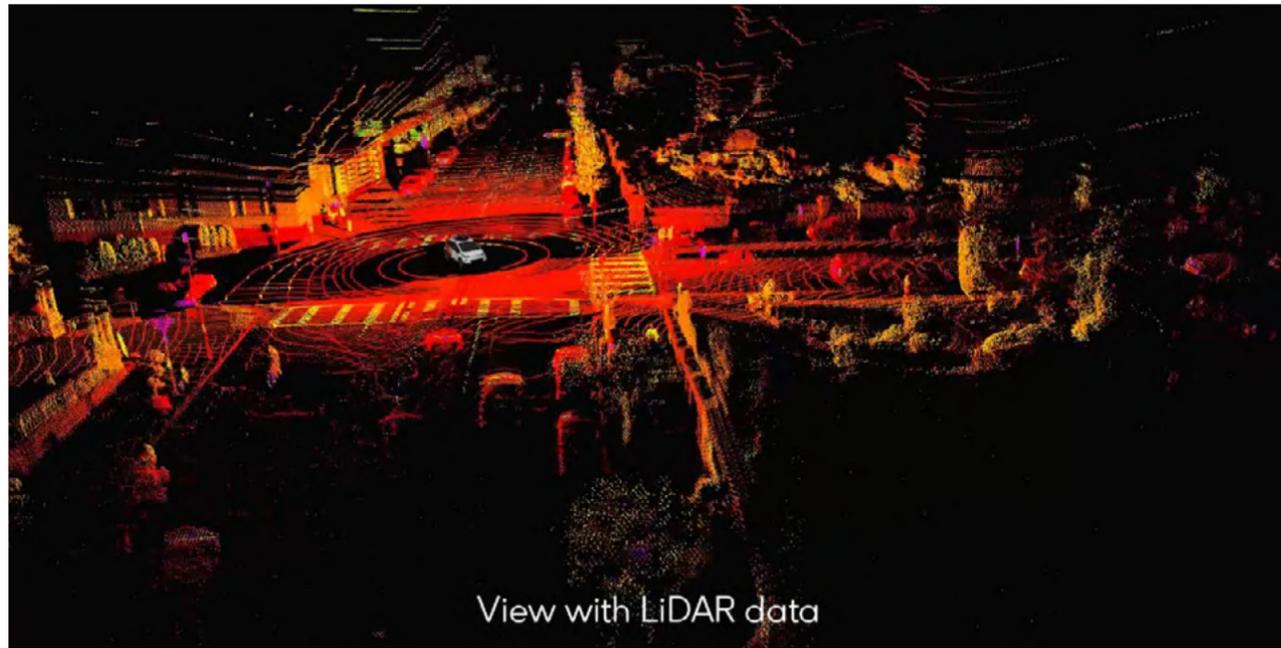
RADAR

RADAR sensors are placed on the Cruise Origin to ensure comprehensive coverage and to complement the data gathered by LiDAR and cameras. These sensors detect the distance, speed, and angle of objects around the vehicle, contributing to a robust 360-degree understanding of the environment. RADAR sensors allow Cruise vehicles to maintain a constant awareness of nearby objects, right down to the centimeter, which is essential for navigating complex urban environments safely.

Moreover, Cruise’s RADAR technology also includes enhanced night vision capabilities, ensuring clear detection around the clock. The company’s computing platforms process the RADAR data alongside inputs from other sensors, facilitating instantaneous and informed decision-making crucial for autonomous driving.

Computing Platform

Cruise’s autonomous vehicle technology relies heavily on its advanced computing platforms, which form the backbone of its operational capabilities. These platforms are designed to



View with LiDAR data of a Cruise AV.
Image credit: Cruise

handle the enormous amount of data generated by the vehicle's sensors, including LiDAR and RADAR. These computing systems use GPUs and custom-designed chips to ensure that data is processed in real-time, enabling the vehicle to make swift and accurate decisions on the road. The robustness of these computing solutions is crucial for the continuous and intensive demands of autonomous driving, where data processing speed and reliability are non-negotiable for safety and efficiency.

Artificial Intelligence

Cruise use AI algorithms are used for object detection, lane detection, obstacle avoidance, and route planning. Moreover, the company uses NLP to enable passengers to communicate with the vehicle using voice commands. This NLP capability has been advanced further to understand more complex queries, reflecting Cruise's

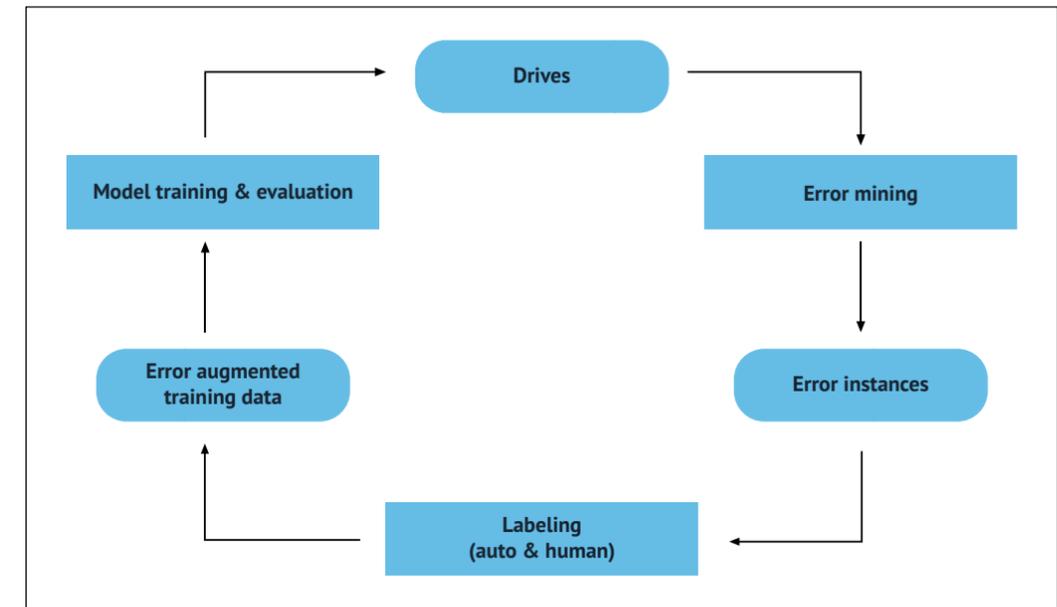
commitment to creating an interactive and user-friendly experience. AI also plays a role in Cruise's Continuous Learning Machine, which automates data collection, labeling, model training, and deployment, ensuring that the vehicle's driving systems improve over time. This machine-learning approach enables Cruise's vehicles to handle the unpredictability of real-world driving scenarios with greater accuracy and safety.

The GM subsidiary has also integrated NLP since 2018 in order to enable passengers to communicate with their AVs using voice commands. Expanding on this, in 2021, Cruise introduced „natural language understanding,” a feature empowering passengers to pose more intricate queries to the vehicle.⁹⁰

Cruise employs a fusion of handcrafted attributes and deep learning to enrich its feature extraction process

from raw sensor data. Their human-designed features are shaped by expert insights into the environment and driving dynamics. These include the car's position, speed, and proximity to other objects. They have introduced a sophisticated DL framework, which adeptly extracts features from images and RADAR data. The framework learns to recognize pivotal driving-related attributes, encompassing object shapes, distances, and velocities. Cruise also adopts multimodal data fusion to strengthen its approach further, merging information from diverse sensors.

A core challenge identified was accurately predicting the intentions of pedestrians and vehicles for making informed decisions. Two strategies are auto-labeling prediction data using the vehicle's perception system and automated error identification through active learning. These concepts are integral to Cruise's Continuous Learning



Cruise's continuous learning machine loop.
Image credit: Cruise

Machine (CLM), which automates data collection, labeling, model training, and deployment. Despite the rarity of certain scenarios, CLM progressively improves predictions through continuous learning. The CLM approach minimizes human intervention and scales to handle even the most intricate longtail problems.

Blockchain

Cruise employs blockchain to secure vehicle data while also facilitating personalized customer experiences. The company has submitted a patent

application for a „Decentralized Distributed Map Using Blockchain”.⁹² The patent aims to address the challenge of maintaining dynamic vehicle mapping information without incurring high costs. Their solution involves sensors that assess the vehicle's surroundings and a discrepancy detector that identifies variations compared to a known navigation map. These differences are transmitted to a blockchain map network, leveraging the blockchain's ability to maintain an updated and reliable record.

Vehicle Applications

The Cruise Origin, Cruise's latest venture, offers a fully autonomous vehicle that lacks mirrors, pedals, or steering wheels. The modular design of the Origin enables it to be upgraded with new sensors or computers without requiring the replacement of the entire fleet. With the capacity to accommodate 4-5 people and the concept of an autonomous bus, the Origin can also be used for deliveries.^{93,94,95,96}



Illustration of the Cruise Origin.
Image credit: Cruise

Volvo

In early January 2022, at the CES consumer electronics show, Volvo unveiled its novel Level 3 autonomous driving system known as Ride Pilot. The name „Ride Pilot“ succinctly conveys its purpose: while the car autonomously drives, Volvo Cars assumes driving responsibility, ensuring driver comfort and peace of mind.⁹⁹

The Ride Pilot system will enable fully autonomous, hands-free driving on specific roads under particular traffic conditions. This involves utilizing OTA software updates in tandem with a cutting-edge sensor configuration. The software is a collaborative effort

between autonomous driving software company Zenseact, Volvo Cars’ in-house developer team, and engineers from Luminar, one of its technology partners.

Sensing

Ride Pilot is able to be installed in the newest XC90 SUV. This electric EV will encompass all necessary components for operating Ride Pilot, including five RADAR sensors, eight cameras, 16 ultrasonic sensors, a LiDAR unit, and the requisite controlling software. These sensors will be factory-installed, and once Volvo completes its testing and obtains approvals, it will likely enable the Ride Pilot feature through an over-the-air update.¹⁰⁰ The LiDAR

sensor will be integrated into the car’s roofline, while the other cameras and sensors will be strategically positioned around the rest of the EX90. These sensors will be able to scan the road ahead and identify pedestrians up to 250 meters away and even small, dark objects like a tire on a black road 120 meters ahead. This technology aims to assist drivers in avoiding road hazards or halting the car when necessary, with the company asserting that it could potentially reduce accidents causing injuries or fatalities by up to 20%.¹⁰¹

OTA Updates

In 2022, Volvo’s Version 1.7 OTA update includes bug fixes, multimedia system

improvements, and Sirius XM radio updates, and for electric vehicles, aims to improve range by modifying the drive system, showcasing the promising potential of vehicle software updates.¹⁰³

Blockchain

When it comes to bolstering the safety and quality of its products throughout the entire supply chain, Volvo utilizes blockchain. This strategy minimizes recall risks and ensures component adherence to rigorous standards. Volvo Cars introduced global cobalt traceability in its batteries through blockchain technology, making it the first automaker to do so. Blockchain improves supply chain transparency by securely recording material origin

and characteristics, making alterations impossible to hide. Volvo has partnered with CATL and LG Chem, as well as blockchain companies like Circular, Oracle, RSBN, RCS Global, and IBM, to implement traceability across battery supply chains, promoting transparency, trust, and ethical practices.



Volvo’s ride pilot hands free system. Image credit: Volvo.

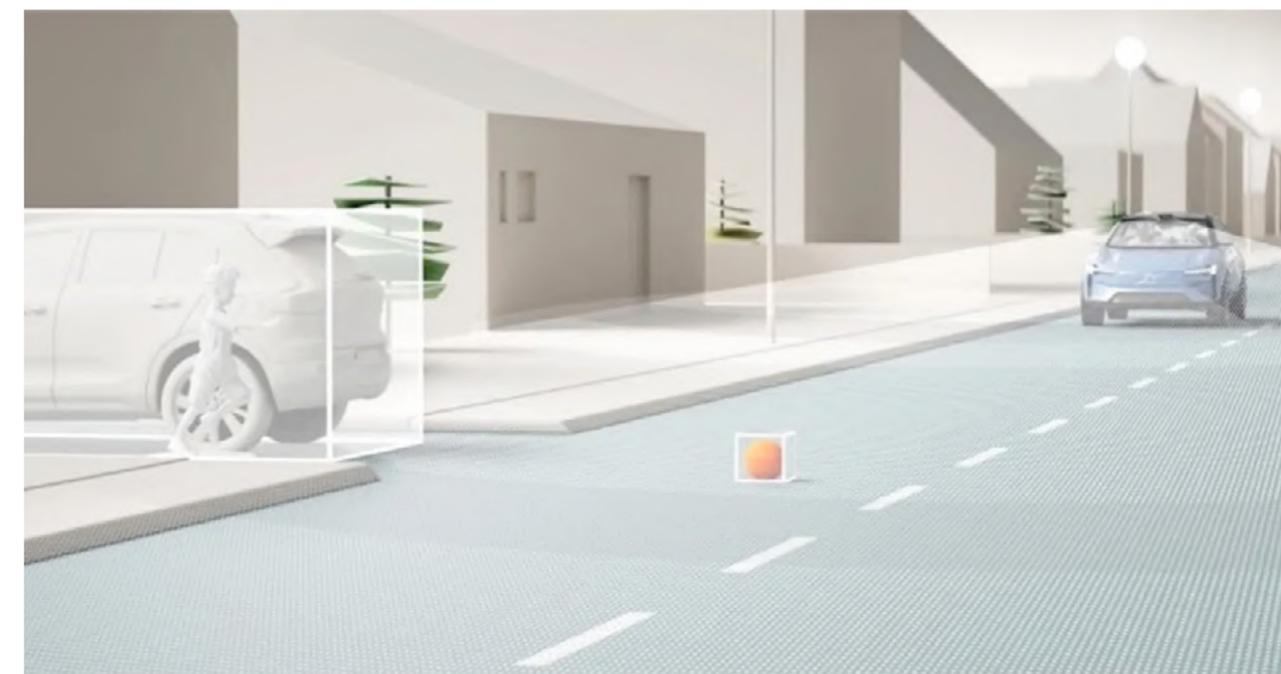


Illustration of a Volvo EX90 detecting obstacles on the street through its Ride Pilot system. Image credit: Volvo

Report Summary

The last three years have seen remarkable advancements in the development of autonomous vehicle, particularly in the fields of computing and communication. Significant investment by leading automakers, ambitious startups and a move towards open-source development has accelerated the move to autonomy.

Developments in sensing technology, such as high-resolution cameras, wider field-of-view cameras, and improved image processing algorithms, have significantly enhanced the capabilities of autonomous vehicles. Furthermore, the infusion of AI into vision systems, utilizing deep learning models like convolutional neural networks (CNNs), has revolutionized the way AVs perceive and understand their surroundings, further improving safety and object detection.

LiDAR technology has also undergone noteworthy transformations. Traditional LiDAR systems with moving parts have given way to more compact and precise solid-state and advanced sensors. Emerging Frequency Modulated Continuous Wave (FMCW) LiDAR, in particular, has enabled real-time distance and

velocity measurements, elevating AV perception. The integration of hybrid LiDAR systems has bolstered object detection and distance assessment, emphasizing the significance of sensor fusion for robust autonomous driving systems.

RADAR sensors, too, have witnessed substantial enhancements, functioning effectively in diverse weather conditions and providing comprehensive 360° coverage around vehicles. Multi-mode RADAR sensors' ability to switch between detection ranges has boosted adaptability, while innovations like Digital Beamforming RADAR have improved object tracking. The shift towards solid-state RADAR, with its elimination of moving parts, has not only increased reliability but also enhanced energy efficiency.

Meanwhile, technologies such as Frequency Modulated Continuous Wave (FMCW) RADAR and 4D RADAR have introduced precise distance and velocity measurements, while Synthetic Aperture RADAR (SAR) has contributed high-resolution imaging for advanced object recognition and perception.

AI and computing have played a central role in AV advancements, particularly with the adoption of Deep Reinforcement Learning and Generative Adversarial Networks (GANs). These technologies support dynamic AV scenarios and facilitate realistic visual generation for object recognition. Robust AI algorithms have become indispensable for AVs to navigate diverse and challenging conditions while maintaining resilience in the face of disturbances and uncertainty.

Furthermore, AI integration with Natural Language Processing (NLP) is transforming vehicle interactions, making them more intuitive and efficient. To ensure seamless operation, cloud-based AI with high-speed connectivity addresses in-vehicle limitations. Edge computing, on the other hand, reduces latency, enhances sensor data handling, and offers reliability and data privacy, optimizing AV operations and traffic management.

Communication technologies are evolving as well, with 5G revolutionizing AV connectivity through faster data speeds, improved safety, and cost reduction. AVs are now equipped to

process information swiftly, enhance connectivity, make informed decisions, and prioritize safety communication even in crowded networks. Over-the-

Air (OTA) updates have become a critical advancement, allowing remote software enhancements for AVs without the need for recalls. However, this convenience also brings challenges such as data security, reliability, data capacity, integration, and regulatory compliance.

Enhancing AV security is paramount, and blockchain technology has emerged as a potential solution, offering secure storage and sharing of AV data, ensuring integrity and transparency without central control.

To further bolster AV security, Intrusion Detection and Prevention Systems (IDPS) have integrated machine learning and AI to enhance detection accuracy and adaptability to evolving threats. These systems utilize sophisticated anomaly detection techniques to identify novel attacks, operate in real-time by analyzing sensor data, and may rely on shared threat intelligence databases for collective threat

response based on shared experiences among vehicles.

In summary, these interconnected advancements in sensing technology, AI, computing, communication, and cybersecurity are reshaping the landscape of autonomous vehicles, offering safer, smarter, and more sustainable mobility solutions.

However, despite the remarkable progress in the engineering of autonomous vehicles, several challenges remain on the horizon. Ensuring robust and reliable cybersecurity measures to protect AVs from cyberattacks is still a significant concern. Additionally, refining the ability of AVs to navigate complex and unpredictable urban environments, handle adverse weather conditions, and effectively communicate with both other vehicles and pedestrians remains a challenge. Balancing AI decision-making with human intervention in critical scenarios presents a persistent ethical and technical challenge.

Looking towards the future, the realm of autonomous vehicles is poised for even more groundbreaking develop-

ments. The next few years are likely to witness a surge of technological breakthroughs that will drastically impact not only passenger cars but transport in general. The integration of next-generation communication networks like 6G will further enhance vehicle-to-everything (V2X) connectivity, leading to more efficient and safer traffic management.

Additionally, advancements in quantum computing could revolutionize data processing capabilities, enabling AVs to make faster and more accurate decisions. Ethical AI will also become a focal point, ensuring that autonomous vehicles make decisions that are not only safe but also morally sound. This era will mark a significant shift towards a more connected, efficient, and sustainable mode of transportation, reshaping our urban landscapes and daily lives.

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Mansfield, TX. USA

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Mouser has 27 offices located around the globe. We conduct business in 21 different languages and 34 currencies. Our global distribution centre is equipped with state-of-the-art wireless warehouse management systems that enable us to process orders 24/7, and deliver near-perfect pick-and-ship operations.

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Image credit: Adobe Stock

Murata Electronics

Hoofddorp, The Netherlands

Murata is a global solution provider and the market leader in the design, manufacture, and supply of advanced, leading-edge electronic components, and multi-functional modules. Murata contributes to the advancement of society and the electronics industry, in close cooperation with its customers and other stakeholders. The European HQ is based in the Netherlands.

Ultrasonic Cleaning Device

To support better vision of surround cameras in various weather condition and climates Murata is currently developing an Ultrasonic Cleaning Device (USCD) to ensure safe autonomous driving and to keep redundancy.

In-cabin Radar

Every year, there have been tragic accidents of young children and babies being left in cars and dying of heatstroke. To avoid these incidents, some regulations and assessments have been proposed in each region. Especially the Euro-NCAP (European New Car Assessment Programme) is taking initiative and has incentivized car manufacturers to incorporate the technology of Child Presence Detection (CPD) to solve this social problem. Murata tackles this with their In-cabin Radar, as one of the most effective methods of CPD. On top of that, that Radar is able to detect vital sign, enabling a more advanced Driver Monitoring System.

Out-cabin Radar

To support better Parking Assist and Automated Parking, Murata has developed a Near Field Out-cabin Radar. Nowadays, Ultrasound sensors have been used for near field functions. However, Murata expects Radar to replace them for a more reliable detection. In addition, besides Parking Assist Murata's Near Field Radar can support automatic door functions like avoiding door collision and gestures to control the door. The extensibility of these functions is also one of the advantages of Radar.

IMU

Autonomous driving opens limitless possibilities, but safety is still the biggest hurdle to move this technology forward. For over 20 years, Murata has been providing its high performance IMUs including accelerometers & combo sensors to the Automotive industry for various safety critical applications. Murata's IMU sensor fusion with GNSS/Perception proofs as a good combination for realizing safe driving in autonomous vehicle. With partners, Murata limits itself not as a component supplier but evolves to develop the technology together with them, bringing the automation to the next level.

Connectivity Modules

To support the connectivity for ADAS application, Murata has promoted

Bluetooth/WiFi modules and V2X modules. Bluetooth/WiFi functionality is the medium to communicate between User-interface and the car for automated parking. V2X is used for the vehicle to anything communication and DSRC and C-V2X are main protocol which are supported by Murata's V2X modules. ADAS needs more reliable products and has a big concern how to measure the heat. Murata's modules main advantages are very good reliability and heat dissipation.

On top of that, Murata's components can be found in various sensor units and ECUs that are necessary for autonomous driving. Looking at a car that is equipped with all technologies that would allow driving at level 3, Murata could provide up to 8.000 passive components like capacitors, inductors, thermistors, and crystals for that - just talking about the ADAS functions like Lidar, Radar, Camera, Driver Monitoring and the ADAS ECU now.

Learn more at: [murata.com](https://www.murata.com)

For Murata radar module page: <https://www.murata.com/en-global/products/connectivitymodule/mmwave-radar/automotive>



MacroFab

Texas, United States and Jalisco, Mexico

The MacroFab technology platform is a digital platform for electronics manufacturing powered by the world's only factory marketplace. With MacroFab's digital platform, electronics engineers, supply chain managers, and production teams can collaborate on building quality products while harnessing real-time supply chain and manufacturing data.

MacroFab's automated and connected digital processes provide real-time intelligence, better supply chain visibility, and increased manufacturing flexibility, which enables companies of any size to optimize, manufacture, and deliver custom electronics with superior quality and speed.

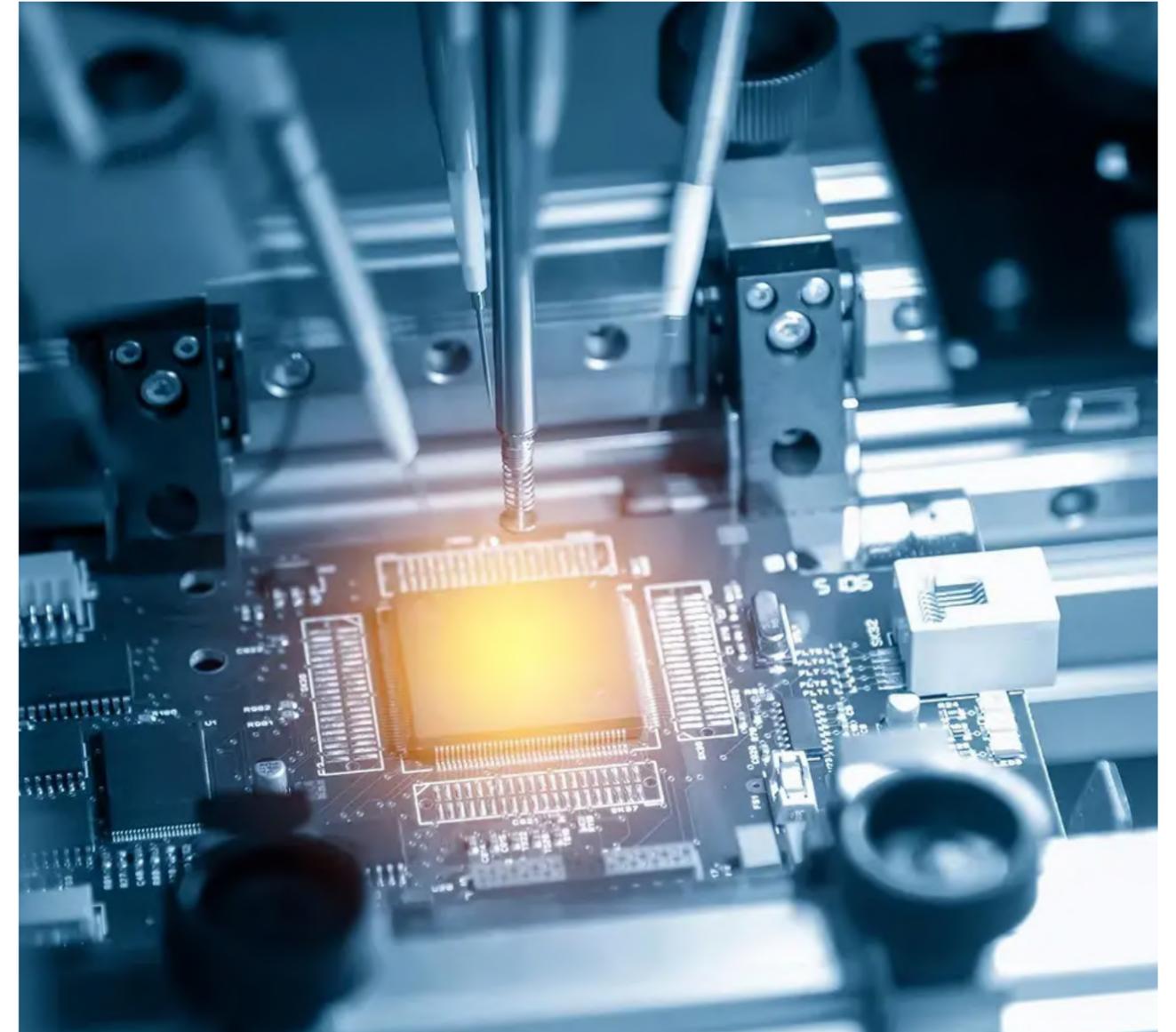
Our technology addresses the fundamental challenge in the electronics industry: the need for efficient, high-quality custom manufacturing. MacroFab's technology platform bypasses conventional roadblocks, reduces lead times and costs, and ultimately yields superior results compared to traditional solutions.

MacroFab is actively contributing to the advancement of autonomous vehicles by providing a streamlined, efficient, and high-quality manufacturing solution for PCBAs. These crucial components power the sensor and control systems essential for autonomous driving technology. This allows companies to focus on innovation and

development while MacroFab handles the rest, cutting lead times and costs associated with autonomous vehicle manufacturing.

In a market where innovation is rapid and time-to-market can be a decisive factor for success, MacroFab's platform plays a crucial role in supporting the intricate electronics that enable autonomous vehicles to navigate, sense their surroundings, and make split-second decisions for safe and efficient travel. Learn more at: macrofab.com

"The technology that supports autonomous vehicles is driving the next generation of transportation and shaping a brighter future."



Nexperia

Nijmegen, Netherlands

Nexperia is an expert in the high-volume production of essential semiconductors: components that are required by every electronic design in the world. The company's extensive portfolio includes diodes, bipolar transistors, ESD protection devices, MOSFETs, GaN FETs and analog & logic ICs. The more than 100 billion products shipped annually, are recognized as benchmarks in efficiency – in process, size, power and performance – with industry-leading small packages that save valuable energy and space.

Nexperia's semiconductors are like the nuts and bolts of electronic design.

Enabling the functionality of almost every commercial design, their efficiency, increased power density, improved thermal management enhance the overall performance in automotive electronics.

Nexperia prioritizes the development of compact and space-efficient package designs, optimizing PCB space and benefiting car manufacturing processes.

Nexperia is dedicated to continuous innovation, focusing not only on traditional silicon but also on leading-edge wide bandgap devices. Our commitment extends to the development of

more efficient power semiconductors that minimize power losses, improve thermal performance, and ensure reliable and long-lasting electronic systems in vehicles. Nexperia's advancements in electronic solutions contribute to increased mileage for car batteries, promoting sustainable transportation in the automotive industry.

Learn more at: [nexperia.com](https://www.nexperia.com)



ADLINK

Taoyuan, Taiwan

For the development of autonomous vehicles, massive amounts of sensor data have to be integrated, and complex real-time calculations must be performed at the edge. There are also difficulties in working with industry-specific communications protocols such as controller area network (CAN) bus—which generic IPCs don't support—and the need for an underlying hardware platform that can withstand the rigors of driving.

ADLINK provides purpose-built platforms that solve many of these challenges—and their flexibility provides a clear path from initial concept to proof-of-service. Several different configurations can be used at various stages of product development.

There are several highlights that tell the difference between ADLINK and other existing solutions:

Safety Features: The computing hardware is equipped with dedicated safety microcontroller unit (MCU) that

monitors the health of the system and, in case of a failure, pulls the vehicle over to a safe stopping place.

Redundancy: Redundant power sources for critical system elements such as the perception electronic control unit (ECU), power management integrated circuit (PMIC), safety MCU, and CAN.

Team up with Industry Partners: ADLINK is the premium partner of Intel, Nvidia, and Arm to acquire the latest design and product roadmap, early sample, and technical support.

Automotive-grade Production Line: Comply with IATF-16949 certification and collaborate with AMR for no touch process in the production line.

ISO 26262 Certified: Following ISO 26262 design compliance to provide safe and reliable hardware for customers' critical vehicle systems.

With cutting-edge autonomous driving computing platforms that pave the

way for safer and more productive travel, ADLINK's vehicle hardware solutions provide you with powerful computing capabilities to fulfill autonomous and advanced driver assistance system (ADAS) technologies as well as rugged design for automotive use.

Learn more about ADLINK Automotive Technology: <https://www.adlinktech.com/en/automotive-computing>

"It's incredibly promising because this really has the potential to make transportation and other sectors safer, more productive, and more efficient," says Liu, the product manager at ADLINK. "With decades of success in embedded computing and rugged designs, ADLINK is ready to elevate your vehicle performance and hasten your development with powerful hardware solutions."



SAE International

Pennsylvania, United States

Our Mission is to advance mobility knowledge and solutions for the benefit of humanity.

Founded in 1905, SAE is a global association of more than 128,000 engineers and related technical experts in the aerospace, automotive and commercial vehicle industries. Our core competencies are life-long learning and voluntary consensus standards development, along with guiding industry with definitions, such as our SAE Levels of Driving Automation.

SAE's broad array of technical, historical, and statistical publications are distributed to customers in more than 65 countries annually. SAE's Training and Professional Development capabilities have been expanded in the past 20 years - SAE now produces more than 450 separate professional development events every year.

Learn more at: saefoundation.org



Partners

Autoware Foundation

Tokyo, Japan

Autoware is the world's leading open-source project for autonomous driving.

Autoware is built on Robot Operating System (ROS) and enables commercial deployment of autonomous driving in a broad range of vehicles and applications.

Autoware is the world's first "all-in-one" open-source software for autonomous driving hosted under the Autoware Foundation. Autoware democratizes autonomous driving technology through open-source development.

The Autoware project is committed to creating synergies among the world's leading technology companies, academic/non-profit organizations and individual contributors. Autoware project lowers the entry barrier to autonomous driving and enables commercial deployment of autonomous vehicles in a broad range of applications. Autoware project is entirely open-source

and hosted on GitHub (<https://github.com/autowarefoundation/autoware>) with an Apache 2.0 license. Autoware has found widespread and international adoption as more than 500 companies use it and runs on more than 30 types of vehicles in more than 20 countries.

Autoware Foundation is a community-driven ecosystem that values transparency and openness while striving for state-of-the-art autonomous driving technology.

Supported by the Autoware Foundation, the Autoware project consists of all the functionality required for autonomous driving (i.e., perception, localization, planning, and control) in a modular architecture with crisply defined interfaces and APIs.

The Autoware open-source software is designed for scalability across a broad range of autonomous applications and developed by applying best practices

and standards to achieve high quality and safety in real-world deployments.

The Autoware Foundation brings together about seventy member organizations from around the world to collaboratively build autonomous driving solutions in an open-source manner. Autoware Foundation also works with more than 20 academic and research institutions in three continents under the Autoware Centers of Excellence initiative. It brings state-of-the-art research and development into tangible applications and deployments.

Autoware Foundation members apply the Autoware open-source project for their autonomous driving applications by using the foundation's best practices (not only in software but also hardware – sensors, compute systems, vehicle sub-systems) to transform their vehicles into autonomous vehicle prototypes. Also, Autoware Foundation member organizations build their product portfolios to complement the

base Autoware project software for commercial deployments, such as simulation tools, Autoware development, integration and testing toolchains, and sensor and computing hardware solutions.

Last but not least, Autoware Foundation is at the epicenter of the Software-Defined Vehicle paradigm through its Open AD Kit initiative – a scalable and modular Autoware software architecture enabling modern automotive software development best practices, including cloud-native development, offering excellent software portability across different safety and non-safety hardware architectures, and over-the-air software updates and mature continuous integration/continuous deployment (CI/CD) through scenarios testing at scale. Autoware Foundation works with alliance partners to realize the Software-Defined Vehicle goals. It contributes to cross-pollination between ecosystem stakeholders such as SOAFEE, Eclipse

SDV, MIH Alliance, AUTOSAR, COVESA and many more.

Through this alliance partnership, Autoware Foundation has a clear roadmap to achieve safety and certifiability for the Autoware project, relying on and supporting collaborative efforts from a plethora of international AV stakeholders.

At the Autoware Foundation, we believe in the promise of autonomous mobility to improve life on Earth. Autonomous vehicles can potentially deliver substantial value to technology developers, mobility users, society and the environment. However, it's still a high entry barrier technology domain.

Self-driving is not yet mainstream because developing autonomous driving technology is a complex and expensive venture, and it currently lacks openness and transparency in how the technology is built when the proprietary approach is preferred. At

Autoware Foundation, we are working on changing the perspective and tone of voice by promoting openness and transparency.

The Autoware project has found widespread and international adoption as more than 500 companies use it, and it runs on more than 30 types of vehicles in more than 20 countries. Autoware project is a collection of designated reference implementations for applications such as autonomous valet parking, autonomous cargo delivery in controlled environments such as warehouses, autonomous people transportation using autonomous buses and shuttles, and many more. The Autoware project's ultimate goal is to provide curb-to-curb autonomous transportation, enabling autonomous vehicles to navigate through densely populated urban areas to highways and serve end-users with a seamless autonomous driving experience. Learn more at: autoware.org



About Wevolver

Wevolver is a global platform and community used by engineers to stay up to date about the latest technologies.

On Wevolver, professional engineers access informative and inspiring content such as articles, videos, podcasts, and reports on robotics, aerospace, semiconductors, advanced manufacturing, and state-of-the-art technologies.

The content on Wevolver is published by tech companies, universities, and individual community members. Next to that, Wevolver collaborates with dozens of technical content creators to develop content for customers and publish that on Wevolver.com

Every month, millions of engineers leverage Wevolver to stay up to date, find knowledge when they are developing products, and to make meaningful connections with each other and the industry.

Wevolver has won the SXSW Innovation Award, the Accenture Innovation Award, and the Top Most Innovative Web Platforms by Fast Company.

Wevolver is how today's engineers stay cutting edge.

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